

## RUNNING HEAD: CHALLENGE/THREAT STATES AND PERFORMANCE

1 The relationship between challenge and threat states and performance: A systematic review

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**Abstract**

The biopsychosocial model of challenge and threat states specifies that these states engender different physiological and behavioural responses in potentially stressful situations. This model has received growing interest in the sport and performance psychology literature. The present systematic review examined whether a challenge state is associated with superior performance than a threat state. Across 38 published studies that conceptualised challenge and threat states in a manner congruent with the biopsychosocial model, support emerged for the performance benefits of a challenge state. There was, however, significant variation in the reviewed studies in terms of the measures of challenge and threat states, tasks, and research designs. The benefits of a challenge state on performance were largely consistent across studies using cognitive, physiological, and dichotomous challenge and threat measures, cognitive and behavioural tasks, and direct experimental, indirect experimental, correlational, and quasi-experimental designs. The results imply that sports coaches, company directors, and teachers might benefit from trying to promote a challenge state in their athletes, employees, and students, respectively. Future research could benefit from a greater consensus on how best to measure challenge and threat states to help synthesise the evidence across studies. Specifically, we recommend that researchers use both cognitive and physiological measures and develop stronger manipulations for experimental studies. Finally, future research should report sufficient information to enable risk of bias assessment.

**Keywords:** Motivated performance situation; biopsychosocial model; stress; cardiovascular reactivity; demand resource evaluations

## CHALLENGE/THREAT STATES AND PERFORMANCE

48           The relationship between challenge and threat states and performance: A systematic review  
49           Understanding individuals' responses to stress is key for optimising performance in contexts  
50 including business, medicine, education, and sport. Although some models explain individuals'  
51 successes and failures in terms of psychology or physiology, one increasingly popular theory  
52 combines these perspectives. The biopsychosocial model (BPSM; Blascovich & Mendes, 2000) of  
53 challenge and threat (CAT) states built on Lazarus and Folkman's (1984) transactional theory of  
54 stress and Dienstbier's (1989) theory of physiological toughness, and has been applied to contexts  
55 as diverse as sport, education, and medicine (Moore, Wilson, Vine, Coussens, & Freeman, 2013;  
56 Roberts, Gale, McGrath, & Wilson, 2015; Seery, Weisbuch, Hetenyi, & Blascovich, 2010). Across  
57 these contexts, CAT states have been associated with different performance outcomes (e.g., Allen &  
58 Blascovich, 1994; Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004), although some studies  
59 have found non-significant or contradictory results (e.g., Feinberg & Aiello, 2010; Laborde,  
60 Lautenbach, & Allen, 2015), and there is notable diversity in how CAT states have been measured  
61 and the research designs employed. To advance our understanding of the impact of CAT states on  
62 performance, the consistency of findings across different methods, and to highlight important  
63 directions for future research, the current article reports a systematic review of the published  
64 literature that utilised the BPSM as a theoretical framework.

65           Central to the BPSM is the assumption that CAT states only occur in motivated performance  
66 situations. Motivated performance situations are goal-relevant, evaluative, and potentially stressful,  
67 requiring adequate active performance in order to ensure wellbeing and personal growth  
68 (Blascovich & Mendes, 2000). Sport competitions, academic exams, and job interviews are typical  
69 examples of such situations. Importantly, according to the BPSM, CAT states represent opposite  
70 ends of a unidimensional continuum rather than two dichotomous states, allowing researchers to  
71 examine relative (rather than absolute) differences in challenge and threat (i.e., greater vs. lesser  
72 challenge or threat; Blascovich, 2008). This contrasts the earlier views of Lazarus and Folkman  
73 (1984), and other researchers (e.g., Skinner & Brewer, 2004), who considered CAT as independent

## CHALLENGE/THREAT STATES AND PERFORMANCE

74 cognitive appraisals that can occur simultaneously. Although these other frameworks offer useful  
75 insights, this review focused only on publications that examined CAT states in the unidimensional  
76 manner hypothesised in the BPSM.

77 CAT states differ in terms of underlying cognitive evaluations and resulting physiological  
78 responses, which are predicted to be linked (Blascovich & Mendes, 2000). According to the  
79 BPSM, challenge states are characterised by the largely subconscious evaluation that one's personal  
80 coping resources match or exceed situational demands. Physiologically, challenge states are  
81 marked by increases in heart rate (HR) and cardiac output (CO), and decreases in total peripheral  
82 resistance (TPR). This cardiovascular pattern is due to sympathetic adrenal medullary activation,  
83 which causes epinephrine release, and dilation of the blood vessels. In contrast, threat states are  
84 characterised by an evaluation that coping resources fall short of situational demands. Threat states  
85 are indexed by little change or small increases in HR, little change or minor decreases in CO, and  
86 little change or small increases in TPR (Tomaka, Blascovich, Kelsey, & Leitten, 1993). This  
87 physiological response is due to additional activation of the pituitary-adrenocortical pathway, which  
88 constricts blood vessels, causes cortisol release, and inhibits the effects of sympathetic-  
89 adrenomedullary activation (Blascovich & Mendes, 2000). Importantly, validation studies showed  
90 that: a) cognitive CAT evaluations and physiological CAT responses were significantly correlated,  
91 and b) cognitive CAT evaluations triggered physiological responses, not vice versa (Blascovich,  
92 2008). These divergent CAT states are predicted to influence performance, with challenge states  
93 being related to superior performance than threat states.

94 The relevance of the BPSM to a range of contexts has led to considerable variation in the  
95 tasks and performance outcomes examined across the literature. For example, studies have  
96 examined the relationship between CAT states and cognitive performance in academic (Seery et al.,  
97 2010), GRE word problem (Chalabaev, Major, Cury, & Sarrazin, 2009), and mental arithmetic  
98 (Kelsey et al., 2000) tasks. Further, Blascovich et al. (2004) found that a cardiovascular CAT  
99 index, measured during a pre-season speech about athletes' sports, predicted batting performance

## CHALLENGE/THREAT STATES AND PERFORMANCE

100 during the season, with a challenge state linked to better performance than a threat state (i.e., more  
101 runs). This initial evidence provided impetus for subsequent research involving behavioural tasks  
102 as varied as simulated surgery (Vine et al., 2013) and cricket batting (Turner et al., 2013).

103 This early research also led to the development of new theories that extended the predictions  
104 of the BPSM (i.e., Theory of Challenge and Threat States in Athletes [TCTSA]; Jones, Meijen,  
105 McCarthy, & Sheffield, 2009; integrated framework of stress, attention, and visuomotor  
106 performance; Vine, Moore, & Wilson, 2016). These theories suggest that CAT states could  
107 influence performance through various mechanisms. For example, the TCTSA predicts that a threat  
108 state may lead to more negative emotions, unfavourable interpretations of emotions, impaired  
109 cognitive functioning, decision-making and anaerobic power, greater self-regulation, increased  
110 reinvestment and avoidance coping, and less effective attention, which may in turn impair  
111 performance (Jones et al., 2009). Further, Vine et al. (2016) argue that a threat state might deter  
112 performance by disrupting attentional and visuomotor control, causing individuals to become  
113 distracted by less relevant (and potentially negative) stimuli at the expense of more important task-  
114 relevant cues. This is in keeping with the original mechanism proposed by Blascovich et al. (2004),  
115 who speculated that attentional resources might be diverted from the task at hand towards the  
116 environment or themselves during a threat state. However, to date, relatively little research has  
117 tested these potential mechanisms (e.g., Moore, Vine, Wilson, & Freeman, 2012).

118 With increasing interest in the BPSM, there has been greater diversity in the  
119 conceptualisation and measurement of CAT states. Indeed, while some authors have used self-  
120 report measures of demand and resource evaluations (e.g., Gildea, Schneider, & Shebilske, 2007),  
121 others have used physiological indices computed from CO and TPR reactivity (i.e., change in CO  
122 and TPR from baseline to post-instruction/task exposure; e.g., Blascovich et al., 2004). Although  
123 both the cognitive evaluations and physiological responses accompanying CAT states are predicted  
124 to influence performance, it is not known which has the strongest effect. Even within these  
125 approaches, little consensus exists regarding standardised measurements. For example, both single-

## CHALLENGE/THREAT STATES AND PERFORMANCE

126 and multi-item self-report measures of cognitive evaluations have been used to calculate either a  
127 ratio (e.g., demands divided by resources), or a difference score (e.g., resources minus demands).  
128 Researchers have also differed in the timing and duration of baseline and post-instruction/task  
129 exposure periods when recording cardiovascular data, and have used different methods to calculate  
130 a single CAT index from CO and TPR reactivity (e.g., difference vs. residualised change scores).

131 In addition to the diversity in the measurement of CAT states and the tasks employed,  
132 studies have adopted different research designs. Some studies have employed experimental  
133 designs, directly manipulating individuals into CAT states and observing performance. For  
134 example, Moore and colleagues (2013) used verbal instructions to elicit CAT states before a golf  
135 putting task, and found that the golfers in the challenge group outperformed those in the threat  
136 group (Moore, Wilson et al., 2013). Other experimental studies have indirectly manipulated CAT  
137 states via an antecedent and then measured performance (e.g., resource appraisals; Turner, Jones,  
138 Sheffield, Barker, & Coffee, 2014). Correlational studies have also been employed, with CAT  
139 states observed before a task and subsequently related to performance (e.g., Turner et al., 2013).  
140 Finally, studies have used quasi-experimental designs, recording CAT states with continuous  
141 measures, and then splitting the sample into CAT groups before examining between-group  
142 differences in performance (e.g., via median split; Gildea et al., 2007).

143 Given the increasing adoption of the BPSM for understanding performance variation during  
144 stressful tasks, aligned with notable diversity in the conceptualisation of CAT states, performance  
145 outcomes, and research designs employed, the primary aim of this systematic review was to  
146 examine the pattern of associations between CAT states and performance outcomes. The secondary  
147 aim was to examine the consistency of this pattern across different conceptualisations of CAT states  
148 (i.e., cognitive evaluations vs. physiological responses vs. dichotomous groups), performance  
149 outcomes (i.e., cognitive vs. behavioural tasks), and research designs (i.e., direct experimental vs.  
150 indirect experimental vs. correlational vs. quasi-experimental designs). Synthesising the current  
151 evidence will provide crucial insight into the utility of the BPSM to explain performance variation

## CHALLENGE/THREAT STATES AND PERFORMANCE

152 under stress, the impact of employing different methods, and highlight important directions and  
153 methodological considerations for future research.

### 154 **Method**

155 This systematic review was conducted in accordance with the Preferred Reporting Items for  
156 Systematic reviews and Meta-Analyses guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). It  
157 involved four steps: (1) initial literature search (including selection of search terms, electronic  
158 databases, and inclusion criteria), (2) screening based on title, (3) screening based on abstract, and  
159 (4) screening based on full text. Two independent assessors completed each step, compared their  
160 records and discussed any disagreements. The assessors searched for relevant articles using the  
161 following databases: MedLine, PsycINFO, and SPORTDiscus (combined in one search) and Web  
162 of Science (in a separate search). The search terms were (“challenge and threat” AND  
163 “performance”). To be included, studies had to fulfil five inclusion criteria: (1) published in  
164 English in a peer-reviewed academic journal, (2) report at least one empirical study, (3) conducted  
165 with healthy human participants, (4) conceptualise CAT in terms of a unidimensional continuum,  
166 and (5) report at least one performance outcome and its association with at least one CAT measure,  
167 or dichotomous CAT groups that were compared on a CAT measure in a manipulation check.

168 To examine the consistency of the pattern of associations between CAT states and  
169 performance within different conceptualisations of CAT states, performance outcomes and research  
170 designs, we used Sallis, Prochaska, and Taylor’s (2000) sum code classification. This classification  
171 focuses on the percentage of studies that demonstrate a statistically significant effect. Further, to  
172 assess the quality and risk of bias in experimental and non-experimental studies, respectively, the  
173 Cochrane Collaboration’s tool for assessing risk of bias (Higgins & Altman, 2008) and the Risk of  
174 Bias Assessment Tool for Nonrandomised Studies (Kim et al., 2013) were used. For experimental  
175 studies, two independent assessors examined random sequence generation (were experimental  
176 conditions assigned randomly?), allocation concealment (could condition allocations have been  
177 foreseen before/during enrolment?), blinding of participants and personnel (were participants and

## CHALLENGE/THREAT STATES AND PERFORMANCE

178 researchers blind to the participants' allocated experimental condition?), blinding of outcome  
179 assessment (were outcome assessors blind to experimental condition?), incomplete outcome data  
180 (were attrition/exclusion rates and reasons reported?), selective reporting (was there a possibility of  
181 selective reporting?), and other sources of bias (Higgins & Altman, 2008). For non-experimental  
182 studies, two independent assessors examined blinding of outcome assessment, incomplete outcome  
183 data, selective reporting, selection of participants (how adequate was the selection of participants?),  
184 confounding variables (was there adequate consideration of confounders?), and intervention  
185 (exposure) measurement (was there performance bias caused by inadequate measurement of  
186 exposure?; Kim et al., 2013).

### 187 **Results**

188 The initial search (conducted in December 2017) yielded 1107 unique results. After  
189 reviewing titles, 155 records remained. After reading abstracts, 59 records remained. After  
190 reviewing full-texts, 30 articles reporting 38 studies with a total of 3257 participants were identified  
191 and included in the review. Figure 1 illustrates the search and screening process. Inter-rater  
192 agreements in the second, third, and fourth step were 96.6%, 84.4%, and 84.7%. Disagreements  
193 were resolved through discussion between the assessors and a third member of the research team.

### 194 **General Study Characteristics**

195 Table 1 presents the characteristics and main outcomes of the included studies. Sample  
196 sizes ranged from 16 to 238 with a mean sample size of 85.7 participants ( $SD = 54.4$ ). Most  
197 samples contained both genders, but four samples were all male (Gildea et al., 2007; Laborde et al.,  
198 2015; Turner et al., 2013), and five samples were all female (Chalabaev et al., 2009; Chalabaev,  
199 Major, Sarrazin, & Cury, 2012; Mendes, Blascovich, Hunter, Lickel, & Jost, 2007; Study 2,  
200 Scheepers, 2017; Turner, Jones, Sheffield, & Cross, 2012). The average age in the 28 studies that  
201 reported this statistic ranged from 11.0 to 36.3 years with an average mean of 22.5 years ( $SD = 4.9$ ).  
202 The remaining studies reported a mode age of 18 years (Quigley, Barrett, & Weinstein, 2002), a  
203 median of 28 years (Roberts et al., 2015), or no age statistic (Blascovich et al., 2004; Chalabaev et



## CHALLENGE/THREAT STATES AND PERFORMANCE

204 al., 2009; Chalabaev et al., 2012; Feinberg & Aiello, 2010; Kelsey et al., 2000; Seery et al., 2010).  
205 Most studies sampled university students, but others incorporated athletes, doctors, adolescents,  
206 academic staff, and non-specified adults.

### 207 **Risk of Bias in Individual Studies**

208 Table 2 presents the risk of bias results. Interrater agreements were 84.1% and 85.8% for  
209 experimental and non-experimental studies, respectively. The assessors resolved disagreements in  
210 discussions with a third member of the research team. In experimental studies, the lowest risk of  
211 bias ratings emerged for “random sequence generation”, “incomplete outcome data”, and “other  
212 sources of bias”, as 88.9%, 77.8%, and 100% of studies received a “low risk of bias” rating,  
213 respectively. Unclear risk of bias was more apparent for “allocation concealment”, “blinding of  
214 participants and personnel”, “blinding of outcome assessment”, and “selective reporting”, with  
215 88.9%, 88.9%, 55.6%, and 100% of studies rated as “unclear risk of bias” respectively. The  
216 assessors rated one study (5.6%) in the “incomplete outcome data” category as “high risk of bias”.

217 In non-experimental studies, a low risk of bias ratings emerged for “blinding of outcome  
218 assessment”, “incomplete outcome data”, “confounding variables”, and “intervention (exposure)  
219 measurement”, as 55.0%, 75.0%, 100%, and 100% of studies in these categories received a “low  
220 risk of bias” rating, respectively. “Selective reporting” and “selection of participants” received  
221 mostly “unclear risk of bias” ratings (100% and 90.0%, respectively). The assessors rated two  
222 studies (10.0%) in the “incomplete outcome data” category as “high risk of bias”.

### 223 **Association between CAT States and Performance**

224 Of the 38 included studies, 28 (74%) found an effect on performance favouring a challenge  
225 state, although three of the observed effects were contingent on an interaction with another variable.  
226 The three interaction effects depended on solo status (performing alone or not; Study 1, White,  
227 2008), performance goals (performance-avoidance or approach goal; Chalabaev et al., 2012), and  
228 integrative task structure (whether concessions on less important aspects of a negotiation tasks led  
229 to gains on more important aspects or not; Study 2, O’Connor, Arnold, & Maurizio, 2010). Of the

## CHALLENGE/THREAT STATES AND PERFORMANCE

230 remaining 10 studies, one found an effect favouring a threat state (Study 1, Feinberg & Aiello,  
231 2010), and nine found no significant effects (Chalabaev et al., 2009; Study 4, Feinberg & Aiello,  
232 2010; Study 2, Gildea et al., 2007; Laborde et al., 2015; Mendes et al., 2007; Quigley et al., 2002;  
233 Rith-Najarian et al., 2014; Sammy et al., 2017; Turner et al., 2014). At least one effect size was  
234 reported in 24 studies, yielding 29 in total: 12 Cohen's  $d$  values ranging from 0.29 to 1.09, 15  $R^2$   
235 values ranging from .06 to .61, one  $sr^2$  of .04, and one  $\eta_p^2$  of .12 (see Table 1). These reflected 11  
236 small, 14 medium, and four large effect sizes (Cohen, 1992).

### 237 **Effects of cognitive, physiological, and dichotomous CAT measures on performance.**

238 Table 3 lists the associations between CAT states and performance based on whether CAT was  
239 analysed as a continuous cognitive, continuous physiological, or dichotomous variable. The  
240 dichotomous category included studies that compared challenge and threat groups in the analysis,  
241 regardless of whether the groups were created by an experimental manipulation or by a median split  
242 of a continuous CAT measure. Studies that reported an association with performance of more than  
243 one CAT measure are included in each relevant category; thus, the number of effects is 43.

244 Sixteen studies reported 17 analyses that examined the association between a cognitive CAT  
245 measure and performance. Thirteen analyses (76%) found a statistically significant effect favouring  
246 a challenge state, with two effects contingent on interactions (Study 1, White, 2008; Chalabaev et  
247 al., 2012). Four analyses found no significant effect (Chalabaev et al., 2009; Laborde et al., 2015;  
248 Quigley et al., 2002; Rith-Najarian et al., 2014). Of the six effect sizes reported, three were small  
249 (Chalabaev et al., 2012; Moore, Young, Freeman, & Sarkar, 2017; Study 1, Moore, Wilson et al.,  
250 2013), two were medium (Study 1, O'Connor et al., 2010; Schneider, 2004), and one was large  
251 (Vine et al., 2015). The majority of the cognitive CAT indices used self-report items from Tomaka  
252 and colleagues' (1993) cognitive appraisal ratio or Schneider's (2008) stressor appraisal scale to  
253 create demand and resource evaluation scores. These scores were combined into a ratio (i.e.,  
254 demands divided by resources; e.g., Quigley et al., 2002) or a difference score (i.e., resources minus

## CHALLENGE/THREAT STATES AND PERFORMANCE

255 demands; e.g., Chalabaev et al., 2012). However, some studies used single-item measures that  
256 assessed the degree to which participants felt challenged or threatened (e.g., Turner et al., 2012).

257       Eleven studies reported 12 analyses that examined the association between a physiological  
258 CAT measure and performance. Eight (67%) found that a challenge cardiovascular response was  
259 associated with better performance than the threat response (Blascovich et al., 2004; Moore et al.,  
260 2017; Scheepers, 2017; Scholl, Moeller, Scheepers, Nuerk, & Sassenberg, 2015; Seery et al., 2010;  
261 Turner et al., 2013; Studies 1 and 2, Turner et al., 2012). Four analyses found no significant effect  
262 (Mendes et al., 2007; Rith-Najarian et al., 2014; Seery et al., 2010; Vine, Freeman, Moore,  
263 Chandra-Ramanan, & Wilson, 2013). Of the 10 effect sizes reported, five were small (Blascovich  
264 et al., 2004; Moore et al., 2017; Scheepers, 2017; Scholl et al., 2015; Seery et al., 2010), and five  
265 were medium (Scholl et al., 2015; Studies 1 and 2, Turner et al., 2012). The physiological CAT  
266 index comprised a sum score of the changes in CO and TPR from baseline to a post-instruction (or  
267 manipulation) period. These changes were determined by using difference scores in all studies in  
268 the “Physiological” group. However, two studies in the “Dichotomous” group used residualised  
269 change scores (i.e., standardised residuals of a regression of post-instruction on baseline values, to  
270 control for differences in baseline values) to create the index (e.g., Moore et al., 2015; Moore, Vine,  
271 Wilson, & Freeman, 2014). Both approaches typically weighted TPR reactivity negatively, so that  
272 a greater value on the summed CAT index was more reflective of a challenge state. Finally, the  
273 timing and duration of physiological data differed between studies. For example, some studies  
274 recorded five minutes of baseline data and one minute after giving task instructions, although they  
275 often only used the final minute of the baseline period in the analyses (e.g., Moore et al., 2014).  
276 Other studies measured five minutes of baseline data and two minutes of reactivity data during the  
277 task, using mean values of the entire time periods (e.g., Blascovich et al., 2004).

278       Only 11 studies included both physiological and cognitive CAT indices, and only three of  
279 these studies reported associations with performance for both indices<sup>1</sup> (Moore et al., 2017; Rith-

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<sup>1</sup> Chalabaev et al.’s (2009) study is not listed here despite reporting performance analyses for the cognitive and physiological variables (i.e., CO and TPR reactivity). This is because the physiological CAT variables were not

## CHALLENGE/THREAT STATES AND PERFORMANCE

280 Najarian et al., 2014; Vine et al., 2013). Moore and colleagues (2017) found that both the cognitive  
281 and physiological CAT measures were related to performance. Rith-Najarian and colleagues (2014)  
282 found that neither measure was related to performance. Vine and colleagues (2013) found that only  
283 the cognitive CAT measure was related to performance, with a challenge state linked with better  
284 performance. Further, only three of the studies that computed both cognitive and physiological  
285 CAT measures provided a correlation between the two indices<sup>2</sup> (Moore et al., 2017; Turner et al.,  
286 2013; Vine et al., 2013). Moore et al. (2017;  $r = .19$ ) and Turner et al. (2013;  $r = .21$ ) found no  
287 significant correlation, whereas Vine et al. (2013) found a significant correlation during the baseline  
288 test ( $r = .32$ ), but not the pressurised test ( $r = -.11$ ).

289 Fifteen studies created dichotomous groups, which were confirmed with a manipulation  
290 check using a cognitive and/or physiological CAT measure. Ten (67%) studies found that the  
291 challenge group significantly outperformed the threat group (Study 2, Feinberg & Aiello, 2010;  
292 Studies 1 and 3, Gildea et al., 2007; Moore et al., 2012; Moore et al., 2014; Moore et al., 2015;  
293 Study 2, Moore, Wilson et al., 2013; Study 2, O'Connor et al., 2010; Scheepers, 2017), with one  
294 effect contingent on an interaction (O'Connor et al., 2010). Furthermore, Feinberg and Aiello  
295 (2010) reported three significant interaction effects between CAT instructions and experimenter  
296 presence. However, they did not report whether challenge was related to better performance than  
297 threat in any of the two experimenter presence conditions, comparing challenge with challenge, and  
298 threat with threat across the two conditions instead. Four studies found no significant effect (Study  
299 4, Feinberg & Aiello, 2010; Study 2, Gildea et al., 2007; Sammy et al., 2017; Turner et al., 2014),  
300 and one study found that participants in the threat condition outperformed those in the challenge  
301 condition, although it should be noted that the manipulation check in this study was only marginally  
302 significant (Study 1, Feinberg & Aiello, 2010). Of the 16 effect sizes reported, six were small

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combined into a single CAT index, which violated the inclusion criteria. However, it is noteworthy that this analysis did find challenge reactivity to be associated with better performance, supporting the contentions of the BPSM.

<sup>2</sup> Two other studies provided associations between cognitive and physiological variables, but did not use a single physiological CAT index (Turner et al., 2012; Quigley et al., 2002). Turner et al. (2012) did not find any significant correlations, although the coefficients were consistent with the BPSM in terms of direction. Quigley et al. (2002) found a marginally significant association between cognitive CAT and CO, but not between cognitive CAT and TPR.

## CHALLENGE/THREAT STATES AND PERFORMANCE

303 (Study 2, Gildea et al., 2007; Moore et al., 2014; Moore et al., 2017; Study 2, O'Connor et al.,  
304 2010; Scheepers, 2017), seven were medium (Study 3, Gildea et al., 2007; Moore et al., 2012;  
305 Study 2, Moore, Wilson et al., 2013; Schneider, 2004; Turner et al., 2014), and three were large  
306 (Study 1, Feinberg & Aiello, 2010; Study 1, Gildea et al., 2007; Moore et al., 2015).

307 **Effects of CAT states on cognitive and behavioural task performance.** The performance  
308 tasks varied across studies, but could be placed into two main categories: Cognitive and  
309 behavioural. Table 4 lists the studies in each category and their corresponding results.

310 Twenty studies reported 23 effects involving cognitive performance outcomes, of which  
311 eight were mathematical (e.g., serial subtraction task; Kelsey et al., 2000). Examples of other tasks  
312 included Stroop (Study 1, Turner et al., 2012), and word-finding (Mendes et al., 2007) tasks.  
313 Fifteen (65%) analyses found that a challenge state was associated with superior performance,  
314 although two of these effects were contingent on an interaction with another variable (Chalabaev et  
315 al., 2012; Study 1, White, 2008). Seven effects were not significant, and one analysis found that  
316 participants performed significantly better in the threat condition (Study 1, Feinberg & Aiello,  
317 2010). Of the 15 effect sizes, four were small (Chalabaev et al., 2012; Scholl et al., 2015; Seery et  
318 al., 2010), nine were medium (Study 3, Gildea et al., 2007; Schneider, 2004; Scholl et al., 2015;  
319 Studies 1 and 2, Turner et al., 2012), and two were large (Study 1, Feinberg & Aiello, 2010; Study  
320 1, Gildea et al., 2007).

321 Nineteen effects involved behavioural tasks such as golf putting (Moore et al., 2012; Moore  
322 et al., 2015; Study 2, Moore, Wilson et al., 2013), cricket batting (Turner et al., 2013), flight  
323 simulation (Vine et al., 2015), and a medical selection practical (Roberts et al., 2015). Sixteen  
324 (84%) effects favoured a challenge state, with one effect qualified by an interaction with another  
325 variable (Study 2, O'Connor et al., 2010). Three effects were not significant (Rith-Najarian et al.,  
326 2014; Sammy et al., 2017; Turner et al., 2014). Of the 15 effect sizes reported, six were small  
327 (Blascovich et al., 2004; Moore et al., 2014; Study 1, Moore, Wilson et al., 2013; Moore et al.,  
328 2017; Study 2, O'Connor et al., 2010), seven were medium (Moore et al., 2012; Study 2, Moore,

## CHALLENGE/THREAT STATES AND PERFORMANCE

329 Wilson et al., 2013; Study 1, O'Connor et al., 2010; Turner et al., 2014; Studies 1 and 2, Turner et  
330 al., 2012), and two were large (Moore et al., 2015; Vine et al., 2015).

331 **Effects of CAT states on performance within different research designs.** Four types of  
332 research designs were used: (1) experiments that directly manipulated CAT states (explicitly  
333 targeting CAT states), (2) experiments that indirectly manipulated CAT states (targeting another  
334 variable, including putative CAT antecedents), (3) correlational studies, and (4) quasi-experiments.  
335 Table 5 lists the studies grouped by research design. Although the “dichotomous” group in Table 3  
336 shares some studies with the “experimental (direct)” and “quasi-experimental” groups, the research  
337 questions pertaining to Table 3 and Table 5 are different. Table 3 is about the type of CAT measure  
338 and analysis, whereas Table 5 is about the type of research design.

339 Six studies reported experiments that directly manipulated participants into CAT states by  
340 framing the task instructions consistent with either a challenge or threat state (i.e., perceptions of  
341 task demands and personal coping resources). Four (67%) studies found that participants in the  
342 challenge group performed significantly better than those in the threat group (Study 2, Feinberg &  
343 Aiello, 2010; Moore et al., 2012; Study 2, Moore, Wilson et al., 2013), although one effect was  
344 qualified by an interaction (Study 2, O'Connor et al., 2010). One study found no significant effect  
345 (Study 4, Feinberg & Aiello, 2010), and one study found that the threat group outperformed the  
346 challenge group (Study 1, Feinberg & Aiello, 2010). Of the five effect sizes, one was small (Study  
347 2, O'Connor et al., 2010), three were medium (Moore et al., 2012; Study 2, Moore, Wilson et al.,  
348 2013), and one was large (Study 1, Feinberg & Aiello, 2010).

349 Twelve studies reported experiments that indirectly manipulated CAT states by  
350 manipulating another variable such as resource appraisals (Turner et al., 2014), perceived effort and  
351 support (Moore et al., 2014), or interpretations of physiological arousal (Moore et al., 2015), and  
352 obtained different CAT responses between groups. Eight (67%) studies found that a challenge state  
353 was associated with superior performance, although one effect was contingent on an interaction  
354 (O'Connor et al., 2010). Four studies found no significant effect (Chalabaev et al., 2009; Mendes et

## CHALLENGE/THREAT STATES AND PERFORMANCE

355 al., 2007; Sammy et al., 2017; Turner et al., 2014). Of the six effect sizes reported, three were small  
356 (Chalabaev et al., 2012; Moore et al., 2014; Scheepers, 2017), two were medium (Study 1,  
357 O'Connor et al., 2010; Turner et al., 2014), and one was large (Moore et al., 2015).

358 Sixteen studies used a correlational design, correlating either a cognitive or physiological  
359 CAT measure with performance. Of the 18 effects in this group, 14 (78%) showed a significant  
360 association between CAT and performance, with a challenge state related to better performance.  
361 Four analyses found no significant association (Laborde et al., 2015; Quigley et al., 2002; Rith-  
362 Najarian et al., 2014; Seery et al., 2010). Of the 12 effect sizes reported, five were small  
363 (Blascovich et al., 2004; Moore et al., 2017; Scholl et al., 2015; Seery et al., 2010), six were  
364 medium (Study 2, Moore, Wilson et al., 2013; Scholl et al., 2015; Studies 1 and 2, Turner et al.,  
365 2012), and one was large (Vine et al., 2015).

366 Finally, four studies used a quasi-experimental approach by dividing the sample into CAT  
367 groups based on scores on a cognitive CAT measure. All four (100%) studies found that  
368 participants in the challenge group performed significantly better than those in the threat group  
369 (Gildea et al., 2007; Schneider, 2004). Of the six effect sizes reported, one was small (Study 2,  
370 Gildea et al., 2007), four were medium (Study 3, Gildea et al., 2007; Schneider, 2004), and one was  
371 large (Study 1, Gildea et al., 2007).

## 372 **Discussion**

373 For over two decades, the BPSM of CAT states has been used as a framework to understand  
374 variations in cognitive, physiological, and behavioural responses in motivated performance  
375 situations (Blascovich & Mendes, 2000). The aim of this systematic review was to examine the  
376 relationship between CAT states and performance, and the consistency of this relationship across  
377 different CAT measures, performance tasks, and research designs. In 28 (74%) of the 38 studies, a  
378 challenge state was related to better performance. Based on statistical significance, the relationship  
379 between CAT states and performance was relatively consistent across different measures of CAT  
380 states (cognitive vs. physiological vs. dichotomous), performance outcomes (cognitive vs.

## CHALLENGE/THREAT STATES AND PERFORMANCE

381 behavioural), and research designs (direct experimental vs. indirect experimental vs. correlational  
382 vs. quasi-experimental), although there were few studies in the direct experimental group. The  
383 common finding that individuals who exhibited a challenge state outperformed individuals who  
384 displayed a threat state, supports the predictions of the BPSM and holds relevance for sports  
385 psychologists, coaches, business managers, educators, and other professionals interested in  
386 optimising human performance.

387         The beneficial effect of a challenge state was generally consistent across different CAT  
388 measures (i.e., cognitive vs. physiological vs. dichotomous). As such, the findings support the  
389 prediction of the BPSM that CAT states occur on both a cognitive (i.e., underlying demand/resource  
390 evaluations) and physiological (i.e., accompanying cardiovascular responses) level, and influence  
391 performance. However, it is noteworthy that studies including the relationships between both CAT  
392 measures and performance found an inconsistent pattern (e.g., Moore et al., 2017; Rith-Najarian et  
393 al., 2014; Turner et al., 2013), implying that more research is needed to compare the two measures  
394 as predictors of performance. In addition, although the BPSM predicts that different demand and  
395 resource evaluations lead to distinct physiological responses (Blascovich, 2008), only three studies  
396 included both cognitive and physiological CAT measures and reported correlations among these  
397 variables (Moore et al., 2017; Turner et al., 2013; Vine et al., 2013). Weak to moderate correlations  
398 were reported in these studies, raising questions about whether demand and resource evaluations  
399 trigger distinct cardiovascular responses, as proposed by the BPSM (Blascovich, 2008). Indeed, the  
400 wider BPSM literature has also demonstrated weak to moderate links between cognitive and  
401 physiological markers of CAT (e.g., Zanstra, Johnston, & Rasbash, 2010).

402         Studies that used a single cognitive measure of CAT states to dichotomise individuals into  
403 CAT groups (e.g., via a median split) also tended to support the superiority of a challenge state  
404 (e.g., Gildea et al., 2007). However, dichotomising CAT states is incongruent with the notion that  
405 they represent opposite ends of a single bipolar continuum (Blascovich & Mendes, 2000). Further,  
406 dichotomising a sample with a median split could lead to problems like loss of statistical power and



## CHALLENGE/THREAT STATES AND PERFORMANCE

407 difficulty in comparing results between studies due to the different cut-off points employed (Altman  
408 & Royston, 2006). Researchers should therefore consider whether it is appropriate to dichotomise  
409 CAT measures and, if so, ensure that the study has sufficient power.

410 This review revealed notable diversity in the recording and calculation of cognitive and  
411 physiological CAT measures. For instance, both single and multiple self-report items assessed  
412 demand and resource evaluations (Schneider, 2008; Tomaka et al., 1993; Turner et al., 2013). In  
413 addition, responses to these items were used to calculate a ratio (i.e., demands divided by resources;  
414 e.g., Moore et al., 2012), or difference (i.e., resources minus demands; e.g., Moore et al., 2013)  
415 score. Moreover, CO and TPR were reported as reactivity (e.g., Blascovich et al., 2004) or  
416 residualised change scores (e.g., Moore et al., 2012). These values were often calculated by  
417 averaging across different durations and time periods (e.g., final minute of baseline and first minute  
418 after receipt of task instructions, Moore et al., 2014; or final two minutes of baseline and first two  
419 minutes of the task itself, Blascovich et al., 2004). The justifications for these variations were not  
420 always clearly articulated and should be made more explicit in future research.

421 Although these variations did not appear to impact the findings, future research would  
422 benefit from adopting a more consistent approach in CAT measurement to facilitate the synthesis of  
423 evidence across studies. If studies adopt different methods to measure CAT states, it is unclear  
424 whether the observed relationships are due to CAT states themselves or the idiosyncratic  
425 measurement processes (e.g., because self-report was employed rather than cardiovascular indices  
426 or a ratio vs. a difference score). Although we encourage future research to contrast the different  
427 ways of measuring CAT states to empirically identify the optimal approach, we make the following  
428 recommendations based on the justifications provided in the current literature. Researchers should  
429 use both cognitive evaluations and cardiovascular responses to measure CAT states, and further  
430 examine their relationship and respective effects on performance. Given the limitations associated  
431 with single-item scales (e.g., lower relative precision than multi-item scales; McHorney, Ware,  
432 Rogers, Raczek, & Lu, 1992), multi-item measures of demand and resource evaluations should be

## CHALLENGE/THREAT STATES AND PERFORMANCE

433 employed (e.g., Schneider, 2008). The scores from these items should then be used to calculate a  
434 difference score, as ratio scores have been discouraged due to their highly nonlinear distribution  
435 (Vine et al., 2013). When measuring the physiological indices of CAT states (i.e., CO and TPR  
436 reactivity), researchers should use comparable time periods and indices. To ensure true resting  
437 values are obtained, researchers should use the final minute of the baseline period (Sherwood,  
438 Allen, Kelsey, Lovallo, & van Doornen, 1990). Further, given the dynamic nature of CAT states  
439 (i.e., reappraisal; Blascovich, 2008), researchers should utilise the first minute after task instructions  
440 or of task exposure. While most research has employed difference scores rather than residualised  
441 change scores, we recommend that researchers consult guidelines and use the approach most  
442 suitable for their data (e.g., Burt & Obradovic, 2013). Finally, CO and TPR reactivity should be  
443 combined into a single CAT index, which is more in keeping with the unidimensional nature of  
444 CAT states, increases reliability, and simplifies analyses (Seery et al., 2010).

445         The risk of bias assessment showed that random sequence generation, incomplete outcome  
446 data, other sources of bias, blinding of outcome assessment, incomplete outcome data, confounding  
447 variables, and intervention (exposure) measurement exhibited a low risk of bias across most studies.  
448 Allocation concealment, blinding of participants and personnel, blinding of outcome assessment,  
449 selection of participants, and selective reporting often exhibited an unclear risk of bias. As only  
450 three studies were rated as high risk of bias, the body of evidence appears to be of adequate quality  
451 overall, but the findings highlight the importance of considering and reporting potential risks in  
452 future studies. For example, researchers should minimise missing physiological and outcome data,  
453 ensure that performance assessors are naive to CAT data, and provide information about allocation  
454 concealment, blinding of participants, personnel and outcome assessment, and selective reporting.

455         Based on statistical significance, there was a relatively consistent relationship between CAT  
456 states and performance on behavioural and cognitive tasks. The notable difference in support for  
457 cognitive vs. behavioural tasks (see Table 4) could have been influenced by the included and  
458 excluded studies. First, although Chalabaev et al. (2009) found that greater CO reactivity and lower

## CHALLENGE/THREAT STATES AND PERFORMANCE

459 TPR reactivity were associated with better cognitive performance separately, the review excluded  
460 this study as no single physiological CAT index was reported. Second, Feinberg and Aiello's  
461 (2010) three studies that manipulated participants into CAT groups using verbal instructions, found  
462 inconsistent effects for CAT states on performance, one of which involved an only marginally  
463 significant manipulation check. As well as being inconsistent with the notion that CAT states are a  
464 continuum (Blascovich & Mendes, 2000), this approach averages data across CAT groups and  
465 individuals who were not successfully manipulated into the required state might have attenuated the  
466 results (i.e., individuals in the challenge group displaying a threat state, and vice versa; Turner et al.,  
467 2013). As such, the weaker effect on cognitive outcomes might have been caused by other  
468 confounding statistical and methodological issues.

469         Studies that directly manipulated CAT states provided support for the superiority of a  
470 challenge state, although only six studies utilised such a design. Four studies found that the  
471 challenge group outperformed the threat group (Study 2, Feinberg & Aiello, 2010; Moore et al.,  
472 2012; Moore, Wilson et al., 2013; O'Connor et al., 2010), and two studies reported null or  
473 contradictory results (Studies 1 and 4, Feinberg & Aiello, 2010). Issues such as the strength and  
474 effectiveness of the CAT manipulation instructions (as well as the limitations noted above) might  
475 explain the heterogeneous results among Feinberg and Aiello's (2010) studies. For example,  
476 Feinberg and Aiello read instructions aloud to participants, whereas Moore et al. (2012, 2013)  
477 delivered standardised instructions from memory more directly to participants. Researchers  
478 employing experimental designs should report the methods used to manipulate participants into  
479 CAT states and use both cognitive and physiological CAT measures as manipulation checks, as the  
480 two measures could yield divergent results.

481         Although two theoretical models (Jones et al., 2009; Vine et al., 2016) have proposed  
482 several potential mechanisms through which CAT states might influence performance, only three  
483 studies included in the review explicitly tested mediation (Moore et al., 2012; Moore, Wilson et al.,  
484 2013 study 2; Vine et al., 2013). Of these studies, only one study reported statistically significant

## CHALLENGE/THREAT STATES AND PERFORMANCE

485 mediation (Moore et al., 2012), with the findings suggesting that CAT states influenced golf-putting  
486 performance primarily via kinematic variables and not through emotional, attentional, or  
487 physiological pathways. Despite this limited evidence for significant mediating processes, studies  
488 have reported that CAT states are associated with different emotional, attentional, and physiological  
489 responses, with a challenge state linked with less cognitive anxiety, more optimal visual attention,  
490 and less muscle activity (Moore et al., 2012; Moore, Wilson et al., 2013 study 2; Vine et al., 2013).  
491 It is vital for research to continue exploring these and other potential underlying mechanisms to  
492 better understand how a challenge state facilitates performance. In particular, research should test  
493 the attentional mechanisms outlined by Vine et al. (2016), and examine whether a threat state  
494 increases the influence of the stimulus-driven system and draws attention away from task-relevant  
495 to less relevant (and potentially negative) stimuli, resulting in suboptimal performance.

496         Several issues emerged as limitations to the present review. First, a meta-analysis may have  
497 provided additional information about the strength of the relationship between CAT states and  
498 performance. However, this was not feasible due to the substantial variability in methodologies  
499 adopted across studies. The variability across studies also hindered the ability to clearly delineate  
500 how strongly the effects were influenced by the CAT measure, task, or research design. Second, as  
501 this review only included published studies, publication bias might have influenced its results.  
502 Third, the sum codes used in Tables 3, 4, and 5 (adopted from Sallis et al., 2000) use arbitrary cut-  
503 off points and refer to patterns of statistical significance, which do not take into account effect sizes.  
504 Finally, while the research team categorised tasks as either cognitive or behavioural, many tasks  
505 required both cognitive input and behavioural execution. For example, golf putting requires  
506 cognition to determine the optimal direction and behavioural control to execute the motor skill.

507         This review highlights key directions for future research. Given that a challenge state  
508 facilitates performance, it is important to identify factors that elicit a challenge state to aid the  
509 development of theory and effective interventions. While some antecedents proposed by the BPSM  
510 (e.g., required effort and support; Moore et al., 2014) and TCTSA (e.g., control, self-efficacy, and

## CHALLENGE/THREAT STATES AND PERFORMANCE

511 achievement goals, Turner et al., 2014) have been investigated, research should examine other  
512 possible antecedents (e.g., danger, uncertainty, familiarity, knowledge, skills, abilities; Blascovich,  
513 2008). Further, although some interventions have received attention (e.g., arousal reappraisal,  
514 Moore et al., 2015), research should examine other interventions aimed at promoting a challenge  
515 state. Finally, the longitudinal (and likely reciprocal) relationship between CAT states and  
516 performance should be explored.

### 517 **Conclusion**

518 To conclude, a challenge state was related to better performance than a threat state in 74%  
519 of studies. The quality of the included studies was generally good, although the risk of bias  
520 assessment identified some areas for improvement (e.g., minimise data loss). This association  
521 between CAT states and performance was relatively consistent across cognitive, physiological, and  
522 dichotomous CAT variables; cognitive and behavioural tasks; and direct experimental, indirect  
523 experimental, correlational, and quasi-experimental designs. Future research would benefit from a  
524 more consistent approach to CAT measurement (e.g., multi-item self-report measures of cognitive  
525 evaluations), to reduce ambiguity and aid the synthesis of results across studies. Furthermore,  
526 researchers should develop challenge-promoting interventions to optimise the performance of  
527 individuals across a range of domains (e.g., sport, academia, business, and medicine).

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## RUNNING HEAD: CHALLENGE/THREAT STATES AND PERFORMANCE

Table 1

### *Summary of Included Studies*

Reference Number	Authors, Year	N	Design	Population	Mean age (years)	CAT	Main Performance Measures	Results	Effect Sizes	
1	Blascovich, Seery, Mugridge, Norris & Weisbuch, 2004	27	CR	Baseball and softball student athletes	N/A	P	Baseball and softball season performance (runs created)	CAT index related to runs created during season; (challenge > threat)	$R^2 = .11$	
2	Chalabaev, Major, Cury & Sarrazin, 2009	27	EX - performance goal	Female undergraduates	N/A	P, C	Multiple-choice score on GRE word problems	Self-reported challenge was unrelated to performance CO and TPR were related to performance, but only examined separately (no CAT index)	N/A	
3	Chalabaev, Major, Sarrazin & Cury, 2012	58	EX - Performance goal (approach, avoidance, control)	Female psychology undergraduates	N/A	C	Score on math word problems from GRE practice book	For those participants who received a performance avoidance goal, challenge was associated with better performance than threat	$R^2 = .06$	
4	Feinberg & Aiello, 2010 <sup>3</sup>	91	EX - CAT appraisal	Undergraduates	N/A	C, DC	Mental arithmetic score	Threat group outperformed challenge group	$d = 0.85$	
		238	EX - CAT appraisal		N/A		C, DC	Mental arithmetic score	Challenge group outperformed threat group	N/A
		54	EX - CAT appraisal		N/A		C, DC	Anagram task score	No significant difference between groups	N/A
5	Gildea, Schneider & Shebilske, 2007	54	QE	Adults and adolescents (all male in studies 1 and 3)	22.5	C, DC	Space Fortress (total scores; used in all studies)	Challenge associated with higher scores than threat across three experiments (not significant in experiment 2)	$d = 1.09$	
		154	QE		19.9		C, DC			$d = 0.29$
		48	QE		24.1		C, DC			$d = 0.65$

<sup>3</sup> Studies 1, 2, and 4 from this publication were included in the systematic review. Study 3 was not included because it did not report the results of the main effect comparison between the CAT conditions.

## CHALLENGE/THREAT STATES AND PERFORMANCE

6	Kelsey et al., 2000	162	CR	Psychology undergraduates	N/A	C	Three arithmetic tasks (number of responses, arithmetic errors)	Number of responses inversely correlated with pre-task evaluations (challenge > threat) Arithmetic errors positively correlated with pre-task evaluations	N/A N/A
7	Laborde, Lautenbach & Allen, 2015	96	CR	Male sport science students	24.8	C	Concentration grid exercise (consecutive numbers clicked in two minutes)	CAT not significantly related to visual search task performance	N/A
8	Mendes, Blascovich, Hunter, Lickel & Jost, 2007	47	EX - 2x2 (confederate ethnicity x confederate accent)	Female students	19.6	P	Word-finding task (number and accuracy of responses)	No significant effect of CAT index on performance in a mediation model (marginally significant trend was found)	N/A
9	Moore, Vine, Freeman & Wilson, 2013	30	EX - training (quiet eye, technical)	Undergraduates without golf putting experience	19.7	C	Golf putting (mean radial error)	Evaluations mediated the relationship between group and mean radial error (challenge associated with smaller radial error than threat)	N/A
10	Moore, Vine, Wilson & Freeman, 2012	127	EX – CAT appraisal	Undergraduates without golf putting experience	19.5	P, C, DC	Golf putting (mean radial error)	Lower mean radial error in challenge group	$d = 0.69$
11	Moore, Vine, Wilson & Freeman, 2014	120	EX - 2x2 (effort x support)	Undergraduates	21.6	P, C, DC	Laparoscopic surgery completion time	Low effort group (challenged) outperformed high effort group (threatened)	$\eta^2_p = .12$
12	Moore, Vine, Wilson & Freeman, 2015	50	EX - Arousal reappraisal	Participants without golf putting experience	20.2	P, DC	Golf putting (mean radial error)	Arousal reappraisal group was more challenged and performed more accurately (lower error)	$d = 0.93$
13	Moore, Wilson, Vine, Coussens & Freeman, 2013	199	CR	Competitive golfers	36.3	C	Golf competition performance	Challenge evaluations were associated with superior competition performance than threat evaluations	$R^2 = .09$
		60	EX – CAT appraisal	Experienced golfers	22.9			Challenge group holed higher percentage	$d = 0.63$

## CHALLENGE/THREAT STATES AND PERFORMANCE

						P, C, DC	Golf putting (putts holed, performance error)	of putts than threat group Challenge group had lower error than threat group	$d = 0.70$
14	Moore, Young, Freeman & Sarkar, 2017	100	CR	Participants engaging in club or university level sports	21.9	P, C	Dart-throwing task	Physiological CAT index and cognitive CAT evaluations related to dart throwing performance (challenge > threat)	$R^2 = 0.08$ $R^2 = 0.11$
15	O'Connor, Arnold & Maurizio, 2010	138	EX - academic focus	Undergraduates	24.8	C	Negotiation task score	Threat associated with lower negotiation outcomes than challenge	$R^2 = .16$
		196	EX - 2x2 (CAT appraisal x task structure)	Undergraduates	22.2	C, DC	Negotiation task score	Challenge group scored better negotiation outcome than threat group in the integrative task structure condition only – no main effect	$d = 0.32$
16	Quigley, Barrett & Weinstein, 2002	74	CR	Psychology undergraduates	18 (mode)	P, C	Four verbal mental arithmetic tasks (attempts, number correct)	No relation between cognitive evaluations and performance (number of attempts made, percentage correct responses) No analysis reported for physiological data	N/A
17	Rith-Najarian, McLaughlin, Sheridan & Nock, 2014	79	CR	Adolescents	14.70	P, C	Independently rated speech performance	No relation between physiological and cognitive measures of CAT and performance before task	N/A
18	Roberts, Gale, McGrath & Wilson, 2015	94	CR	Doctors	28 (median)	C	Overall station performance score	CAT predicted station performance (threat < challenge)	N/A
19	Sammy et al., 2017	54	EX – Arousal reappraisal	Undergraduates	21.7	P, C, DC	Dart throwing task	Arousal reappraisal group more challenged on physiological index and evaluations, but not better on dart throwing task	N/A
20	Scheepers, 2017	103	EX – 2x2 (Group status x group legitimacy)	Female undergraduates	21	P, DC	Pattern recognition task	CAT index negatively correlated with performance (higher challenge – lower response times)	$R^2 = 0.07$

N/A

## CHALLENGE/THREAT STATES AND PERFORMANCE

21	Schneider, 2004	59	QE	Undergraduates	21	C, DC	Mental arithmetic performance (responses, errors)	High status group was more challenged and outperformed low status group Threat group gave fewer responses Threat group made more errors CAT predicted percent correct (threat < challenge)	$d = -0.78$ $d = 0.53$ $r = -.33$
22	Schneider, Rench, Lyons & Riffle, 2012	152	CR	Psychology undergraduates	20.3	C	Mental arithmetic score (responses and accuracy)	Cognitive evaluations were negatively related with performance (threat < challenge)	N/A
23	Scholl, Moeller, Scheepers, Nuerk & Sassenberg, 2015	50	CR	Undergraduates	20.0	P	Number bisection task <sup>4</sup> errors made	Physiological CAT index was negatively related with number of errors made in all task conditions (challenge associated with less errors than threat)	$R^2 = .21$ $R^2 = .20$ $R^2 = .11$ $R^2 = .16$
24	Seery, Weisbuch, Hetenyi & Blascovich, 2010	95	CR	Undergraduates	N/A	P	University course grades	Cardiovascular CAT (academic interests speech) predicted course grades (challenge > threat) No association found for general test taking speech	$sr^2 = .04$ N/A
25	Turner, Jones, Sheffield, Barker & Coffee, 2014	46	EX - resource appraisals	Undergraduates and academic staff	21.7	P, DC	Bean bag throwing score	Performance not significantly higher in challenge group	$d = 0.50$
26	Turner, Jones, Sheffield & Cross, 2012	25	CR	Academic staff members	34.0	P, C	Modified Stroop accuracy and latency	Cardiovascular challenge responses predicted superior performance over threat responses in both studies	$R^2 = .16$
		21	CR	Female netball players	21.1	P, C	Netball shooting score		$R^2 = .14$
27	Turner et al., 2013	42	CR	Male elite-level cricketers	16.5	P, C	Cricket batting task (runs awarded by coaching staff)	Physiological CAT associated with batting performance (challenge > threat) Cognitive evaluations not associated with performance	N/A N/A

<sup>4</sup> Analyses were only provided for each of the four sub-conditions of the number bisection task. The authors did not report on a total performance score. Thus, four values are reported in the “Effect Sizes” column.

## CHALLENGE/THREAT STATES AND PERFORMANCE

28	Vine, Freeman, Moore, Chandra-Ramanan & Wilson, 2013	52	CR	Final-year medical students	20.5	P, C	Laparoscopic surgery task completion time	Cognitive evaluations associated with performance under pressure (challenge > threat) Relationship not mediated by physiological CAT index	N/A N/A
29	Vine et al., 2015	16	CR	Active pilots	34.8	C	Flight simulator metrics	Challenge evaluation associated with better performance than threat	$R^2 = .61$
30	White, 2008	128	EX - Solo status manipulation	Undergraduates	19.1	C	Math test scores	Challenge associated with higher math test scores than threat	N/A
		90	EX - Solo status manipulation		19.5	C	Recall task score	Challenge was only associated with better performance than threat under solo status.	N/A
							Math test score	Challenge associated with higher math test scores than threat	N/A

*Note.* CAT = Challenge and threat variables recorded, CR = Correlational, DC = Dichotomous (challenge group vs. threat group), EX = Experimental, QE = Quasi-experimental, C = Cognitive, P = Physiological.



RUNNING HEAD: CHALLENGE/THREAT STATES AND PERFORMANCE

Table 2

*Risk of Bias Assessment Results*

<i>Experimental Studies</i>								
Reference Number		Random Sequence Generation	Allocation Concealment	Blinding of Participants and Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting	Other Sources of Bias
2		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
3		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
4	Study 1	Low	Unclear	Unclear	Low	Low	Unclear	Low
	Study 2	Low	Unclear	Unclear	Low	Low	Unclear	Low
	Study 3	Unclear	Unclear	Unclear	Low	Low	Unclear	Low
8		Low	Low	Low	Unclear	Unclear	Unclear	Low
9		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
10		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
11		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
12		Low	Unclear	Unclear	Unclear	Unclear	Unclear	Low
13	Study 2	Low	Unclear	Unclear	Unclear	Low	Unclear	Low
15	Study 1	Low	Unclear	Unclear	Low	Low	Unclear	Low
	Study 2	Low	Unclear	Unclear	Low	Low	Unclear	Low
19		Low	Unclear	Unclear	Unclear	Low	Unclear	Low
20		Low	Low	Low	Low	Unclear	Unclear	Low
25		Low	Unclear	Unclear	Unclear	High	Unclear	Low
30	Study 1	Unclear	Unclear	Unclear	Low	Low	Unclear	Low
	Study 2	Low	Unclear	Unclear	Low	Low	Unclear	Low
<i>Non-experimental Studies</i>								
		Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting	Selection of Participants	Confounding Variables	Intervention (Exposure) Measurement	
1		Low	Unclear	Unclear	Unclear	Low	Low	
5	Study 1	Low	Low	Unclear	Unclear	Low	Low	
	Study 2	Low	Low	Unclear	Unclear	Low	Low	
	Study 3	Low	Low	Unclear	Unclear	Low	Low	
6		Unclear	Low	Unclear	Unclear	Low	Low	
7		Low	Low	Unclear	Unclear	Low	Low	
13	Study 1	Low	Low	Unclear	Unclear	Low	Low	
14		Low	Low	Unclear	Unclear	Low	Low	
16		Unclear	Low	Unclear	Unclear	Low	Low	
17		Unclear	Low	Unclear	Unclear	Low	Low	
18		Low	Low	Unclear	Low	Low	Low	
21		Unclear	High	Unclear	Unclear	Low	Low	
22		Unclear	Low	Unclear	Unclear	Low	Low	
23		Low	Unclear	Unclear	Unclear	Low	Low	
24		Unclear	High	Unclear	Unclear	Low	Low	
26	Study 1	Low	Low	Unclear	Unclear	Low	Low	
	Study 2	Unclear	Low	Unclear	Unclear	Low	Low	
27		Unclear	Unclear	Unclear	Unclear	Low	Low	
28		Unclear	Low	Unclear	Unclear	Low	Low	
29		Low	Low	Unclear	Low	Low	Low	

*Note.* For the “Reference Number” column coding, please consult the corresponding column in Table 1.

## CHALLENGE/THREAT STATES AND PERFORMANCE

Table 3

*Effects on Performance of Cognitive, Physiological, and Dichotomous CAT Variables*

CAT Variable	Reference Number	Number of Effects	Percentage of Effects Supporting the Association			Sum Code
			Positive	Negative	None	
Cognitive	- 2, 3, 6, 7, 9, 13, 14, 15, 16, 17, 18, 22, 27, 28, 29, 30	17	76	0	24	++
Physiological	- 1, 8, 14, 17, 20, 23, 24, 26, 27, 28	12	67	0	33	++
Dichotomous	- 4, 5, 10, 11, 12, 13, 15, 19, 20, 21, 25	15	67	7	27	++

*Note.* Percentages are rounded to integers so do not always total 100. The “Sum Code” was adapted from Sallis, Prochaska, and Taylor (2000): “0” indicates that 0 – 33% of the supported an association, “?” indicates that 34 – 59% of the studies supported the association, and “+” indicates that 60% or more of the studies supported the association. Codes are doubled (“??”, “00”, or “++” when four or more studies supported the association/lack of association). For the “Reference Number” column coding, please consult the corresponding column in table 1.

## CHALLENGE/THREAT STATES AND PERFORMANCE

Table 4

### *Effects of CAT States on Cognitive and Behavioural Task Performance*

Performance Outcome	Reference Number	Number of Effects	Percentage of Effects Supporting the Association			Sum Code
			Positive	Negative	None	
Cognitive	- 2, 3, 4, 5, 6, 7, 8, 16, 20, 21, 22, 23, 24, 26, 30	23	65	4	30	++
Behavioural	- 1, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 25, 26, 27, 28, 29	19	84	0	16	++

*Note.* Percentages are rounded to integers so do not always total 100. The “Sum Code” was adapted from Sallis et al. (2000): “0” indicates that 0 – 33% of the supported an association, “?” indicates that 34 – 59% of the studies supported the association, and “+” indicates that 60% or more of the studies supported the association. Codes are doubled (“??”, “00”, or “++” when four or more studies supported the association/lack of association). For the “Reference Number” column coding, please consult the corresponding column in table 1.

## CHALLENGE/THREAT STATES AND PERFORMANCE

Table 5

### *Effects of CAT States on Performance Within Different Research Designs*

Research Design	Reference Number	Number of Effects	Percentage of Effects Supporting the Association			Sum Code
			Positive	Negative	None	
Experimental (direct)	- 4, 10, 13, 15	6	67	17	17	++
Experimental (indirect)	- 2, 3, 8, 9, 11, 12, 15, 19, 20, 25, 30	12	67	0	33	++
Correlational	- 1, 6, 7, 13, 14, 16, 17, 18, 22, 23, 24, 26, 27, 28, 29	18	78	0	22	++
Quasi-Experimental	- 5, 21	4	100	0	0	++

*Note.* Percentages are rounded to integers so do not always total 100. The “Sum Code” was adapted from Sallis et al. (2000): “0” indicates that 0 – 33% of the supported an association, “?” indicates that 34 – 59% of the studies supported the association, and “+” indicates that 60% or more of the studies supported the association. Codes are doubled (“??”, “00”, or “++” when four or more studies supported the association/lack of association). For the “Reference Number” column coding, please consult the corresponding column in table 1.

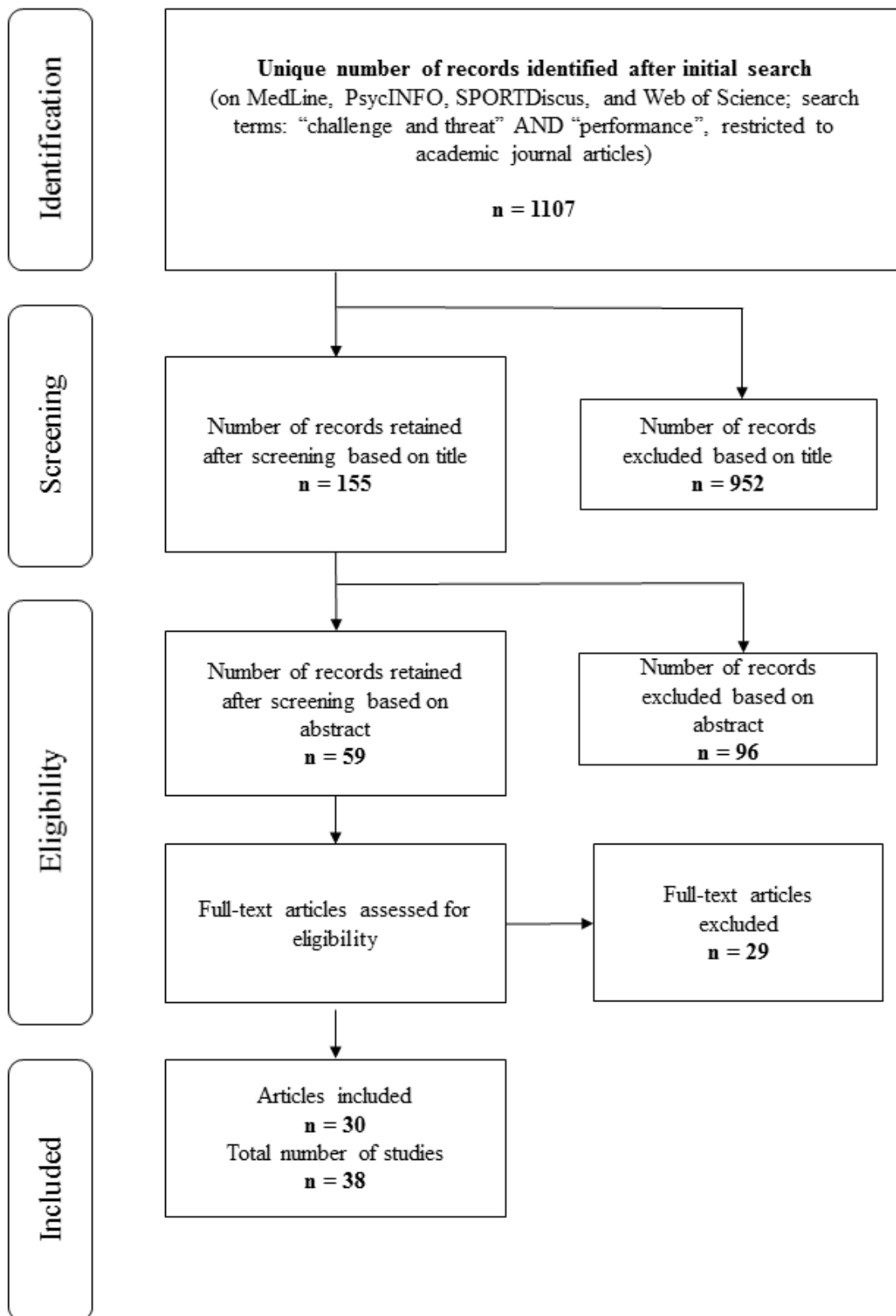


Figure 1. Systematic review search and screening procedure.