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Predicting athletic performance from cardiovascular indexes of challenge and threat☆

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Abstract

This study examined the relationship between pre-performance motivational states (challenge vs. threat) and subsequent performance in athletic competition. Prior to the season, college baseball and softball players imagined and gave a speech about a specific baseball/softball playing situation while cardiovascular indexes of challenge and threat were recorded. These physiological challenge/threat indexes significantly predicted athletic performance during the subsequent season, such that players who experienced challenge in the laboratory performed better relative to those who experienced threat. The implications for personnel selection and the biopsychosocial model of challenge and threat are discussed.

Keywords: Challenge and threat; Motivational states; Athletic performance; Cardiovascular reactivity

Predicting individual performance is important in domains ranging from adherence to medical treatment regimens to personnel selection. Indeed, personnel decisions, whether for admitting applicants to college, graduate, or professional school; hiring or promoting within corporations; or drafting athletes for professional sports teams; often depend on such predictions. Though, arguably, one can predict future performance from past performance, differences between past performance and future performance settings, such as level (e.g., high school vs. college; college vs. the work place; subordinate vs. supervisory role) or substance (e.g., managing an oil company vs. a computer company), may reduce the predictive validity of past for future performance.

Predicting performance also rests on motivational theory and research. For the past decade, we have examined motivational challenge and threat states in performance situations as we developed and tested our biopsychosocial model of challenge and threat (e.g., Blascovich & Mendes, 2000; Blascovich & Tomaka, 1996). An important aspect of this work has been the validation of patterns of cardiovascular responses that distinguish challenge from threat in motivated performance situations.

We have validated these cardiovascular indexes using correlational (e.g., Tomaka, Blascovich, Kelsey, & Leitten, 1993) and experimental approaches (e.g., Tomaka, Blascovich, Kibler, & Ernst, 1997). Additionally, much of our substantive research using these cardiovascular challenge and threat indexes provides convergent validation for them (e.g., Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001; Blascovich, Mendes, Hunter, & Salomon, 1999; Mendes, Blascovich, Major, & Seery, 2001). Although our empirical studies demonstrate that challenge is typically associated with better performance relative to threat, we have yet to establish the predictive validity of these indexes over longer intervals.

The biopsychosocial model of challenge and threat

Our biopsychosocial (BPS) model applies to motivated performance situations, those defined as goal-relevant

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and, hence, task engaging for individuals, and that require instrumental cognitive responses (Blascovich & Mendes, 2000). Examples include test taking, speech giving, interpersonal negotiations, game playing, and athletic competition.

According to the BPS, given task engagement, whether individuals experience challenge or threat in a motivated performance situation depends on their relative evaluations of relevant demands and resources. Resource components include skills, knowledge, and abilities; certain dispositions; and external support. Demand components include danger, uncertainty, and required effort. Challenge occurs when evaluated resources meet or exceed evaluated demands, whereas threat occurs when demands exceed resources.

Although challenge and threat can be indexed via self-report, we believe these states are often best indexed using physiological measures unaffected by the limitations associated with self-report, particularly in the context of predicting performance. For example, athletes competing for a starting position or roster spot may hesitate to admit that they have doubts about their ability to perform. Additionally, athletes, like many others, may not be able to reflect accurately on their inner states and experiences regarding motivational states (see Nisbett & Wilson, 1977). Even if individuals could subjectively report motivational states such as challenge and threat accurately, interrupting their performance might distort these self-report responses. Physiological indexes avoid such problems because they are covert and difficult to consciously control.

A set of four cardiovascular measures confirms task engagement and differentiates challenge and threat: heart rate (HR); ventricular contractility (VC), an index of the left ventricle's contractile force; cardiac output (CO), the amount of blood in liters pumped by the heart per minute; and total peripheral resistance (TPR), an index of net constriction vs. dilation in the arterial system.[1] For all four measures, we compute reactivity scores by subtracting baseline resting response levels from performance levels, as is typical in psychophysiological studies.

Task engagement—necessary for both challenge and threat—is indexed by increases in HR and VC. Given task engagement, challenge is indexed by an increase in CO and a decrease in TPR, whereas threat is indexed by little or no change in CO and no change or an increase in TPR. Dienstbier's (1989) theory of psychophysiological toughness provides the theoretical underpinnings for these observable physiological changes; specifically, differential activation of the sympathetic–adrenomedullary (SAM) and pituitary–adrenocortical (PAC) axes (Blascovich & Tomaka, 1996; Dienstbier, 1989). Both challenge and threat are hypothesized to result in heightened SAM activation, but threat also results in heightened PAC activation, which inhibits vasodilation—mediated by the release of epinephrine—that would otherwise occur.[2]

Challenge, threat, and future athletic performance

We believe the BPS model applies to athletic performance situations, but for practical reasons, challenge and threat research using physiological indexes has thus far been limited to minimally metabolically demanding situations. Physiological responses to physical exertion can complicate and possibly mask the cardiovascular changes that differentiate challenge and threat, making accurate measurement difficult if not impossible. Additionally, the necessary physiological recording equipment is sensitive to movement artifact, such that the large muscle movements necessary for athletic performance can artifactually render recorded physiological data unusable.

Hence, to ascertain the predictive validity between challenge and threat motivational states and athletic performance, we relied on, what we believe is a viable alternative: the relationship between athletes' challenge and threat responses while imagining and giving a speech about playing their sport and the outcome of their performance during the subsequent season. The validity of this alternative rests on a reasonable assumption, that the resource and demand evaluations that occur during athletic performance will also be evoked while one is engaged in a less metabolically demanding motivated performance situation related to the actual athletic performance—such as giving a relevant speech on how to cope with a potentially threatening situation in a baseball game—because the sometimes-subtle factors that influence demand and resource evaluations operate on a psychological rather than a physical level. For example, a player who has pangs of doubt about his or her ability during a critical game situation may experience threat while imagining and talking

[1] For presentational purposes, VC is calculated by multiplying pre-ejection period by −1, where pre-ejection period represents the time in milliseconds in the cardiac cycle from initiation of ventricular depolarization to opening of the aortic valve and ejection of blood; a larger VC value thus corresponds to greater contractility. TPR is calculated by dividing mean arterial pressure by cardiac output and multiplying the total by 80 (Sherwood, Allen, Fahrenberg, Kelsey, Lovallo, & van Dooren, 1990).

[2] Although CO and TPR should be affected by the release of epinephrine that accompanies challenge, it is not clear that VC should also be affected, at least to the same extent. Accordingly, VC does not always differentiate challenge and threat, so it is best used as a measure of task engagement because it does increase under both challenge and threat. However, given increases in VC from baseline, it is not clear whether observed differences reflect differences in challenge vs. threat or task engagement; thus, we used HR as the primary measure of task engagement and VC as the secondary measure.

about the same type of critical situation. On the other hand, a player who has confidence in his or her competence in the situation may experience challenge while imagining it. We argue that in both cases, imagining and talking about the critical situation would be goal-relevant and thus task engaging, especially for individuals for whom the critical situation is particularly self- or goal-relevant.

Hypotheses

We hypothesized that athletes who experience challenge while imagining and talking about playing their sport would perform better during subsequent competition than athletes who experience threat, presumably because they would also be more likely to be challenged during games. In other words, some athletes should have a tendency to experience a positive motivational state (challenge), whereas others should have a tendency to experience a negative motivational state (threat), a difference that should be reflected in subsequent performance statistics.

Method

Participants

Thirty-four student-athletes (non-pitchers) on the varsity baseball (male) and softball (female) teams at the University of California, Santa Barbara, volunteered to participate in the study. Data from three participants were excluded because the players did not play in the subsequent conference season and, hence, had no performance statistics. Finally, for technical reasons it was not possible to score the physiological data from four participants; they were excluded, leaving 27 total batters (14 softball players and 13 baseball players).

Procedures

Participants arrived at the laboratory individually. An experimenter greeted them, led them into an experimental testing room, and applied the sensors necessary to record impedance cardiography (ZKG), electrocardiography (EKG), and continuous blood pressure data. Participants then sat in a comfortable armchair for the remainder of the study. After the experimenter left the testing room, participants listened to an audio recording instructing them to sit quietly until they received further instructions. Subsequently, 5 min of baseline physiological data were recorded.

Following the baseline period, participants gave the first of two 2-min speeches, the order of which was counterbalanced. Just prior to the sport-relevant speech, participants listened to another audiotaped recording instructing them to imagine themselves in the NCAA baseball (or softball) regional playoffs with their team, at bat in the final regulation inning with the outcome of the game on the line. Participants received instructions to discuss their feelings about being in that situation, their thoughts about going from the on-deck circle to the batter's box, and how they expected to perform and why? In the sport-irrelevant speech, participants heard instructions to talk about their strengths and weaknesses as a friend, what they look for in a friend, and the qualities that make a good friend. We designed and included this speech as a control for speech-giving in general and included it as a covariate in analyses (see Section analytical strategy). This control allowed us to partial out any challenge/threat effects for speech-giving in general from the criterion baseball/softball speech.

For both speeches, participants had 1 min to prepare mentally before they began. If participants stopped speaking before 2 min had elapsed, the experimenter prompted them via intercom with one of the relevant speech themes. Participants rested for a second 5-min baseline period between speeches. Finally, all recording devices and sensors were removed and each participant was thoroughly debriefed.

The laboratory portion of the study was completed in the fall, 4–6 months before the start of the baseball and softball seasons. Players and coaches were not informed of laboratory results. Performance statistics were collected when competition had ceased for the year.

Results

Reactivity

For all cardiovascular variables, we examined reactivity, or the difference between the final minute of the initial baseline period and the mean of the two speech minutes.

Task engagement

Because challenge and threat assume goal relevance and task engagement, we confirmed that participants were engaged in the speech tasks by testing mean HR and VC reactivity against zero. The mean HR increase during the friend speech was significantly greater than zero ($M = 12.71$, $SD = 7.34$), $t(26) = 8.99$, $p < .001$, as was the mean VC increase ($M = 4.33$, $SD = 7.55$), $t(26) = 2.98$, $p < .01$. During the sport speech, the mean HR increase was significantly greater than zero ($M = 15.01$, $SD = 8.32$), $t(26) = 9.37$, $p < .001$, as was the mean VC increase ($M = 6.00$, $SD = 6.21$), $t(26) = 5.02$, $p < .001$. These results indicate that participants as a group were engaged by both speech tasks, allowing us to examine the specific cardiovascular indexes of challenge and threat.[3]

Assessing athletic performance

Following James (1988), a noted baseball statistician, we used runs created as our criterion performance measure. James (1988) argued that this measure captures more of the variance of offensive baseball performance (i.e., hitting) than other indexes. Runs created by a batter over a season are calculated as follows: (hits + walks) × (total bases)/(at bats + walks). Runs created is a well-accepted standard for assessing batting performance. We also used statistics for Big West conference games rather than pre-season games. We excluded non-conference games to minimize both coaches' line-up experimentation and padded statistics registered against weaker opponents.

Predicting athletic performance

Analytical strategy

We used hierarchical multiple regression in two steps to predict conference batting performance with cardiovascular reactivity[4] during the sport speech. Step 1 included three control variables: team membership (baseball vs. softball), baseline variable level, and control (friend) speech reactivity. No effect was found for speech order so it was excluded from analyses. Step 2 added sport speech reactivity, the predictor of interest. We controlled for team membership because differences exist between baseball and softball (e.g., nine innings per game in baseball but seven in softball); baseline variable level because resting cardiovascular values can be related to magnitude of reactivity; and friend speech reactivity because we sought to isolate responses during the sport speech that were specifically due to imagining athletic performance, not just giving a speech in general. The topic of the friend speech was chosen so as to be self-relevant yet unrelated to baseball. Although challenge and threat indexes ultimately depend on a pattern of cardiovascular responses, for the sake of interpretability we first considered TPR and CO individually.

Total peripheral resistance

In the regression for TPR ($M = -.43$, $SD = 95.41$), the portion of variance in runs created that was accounted for by the addition of Step 2 was significantly greater than zero, step $R^2 = .10$, $p = .05$. As expected, a decrease in TPR during the sport speech—consistent with challenge—was associated with more runs created, or better performance during the subsequent season ($b = -.023$, $\beta = -.40$).

Cardiac output

In the regression for CO ($M = .0019$, $SD = 1.15$), the addition of Step 2 accounted for a marginal portion of variance in runs created, step $R^2 = .08$, $p < .10$. Mirroring the TPR results, an increase in CO during the sport speech—consistent with challenge—was marginally associated with more runs created ($b = 1.98$, $\beta = .41$).

Challenge and threat index

Finally, we calculated a single challenge and threat index for each cardiovascular term in the model (i.e., baseline, friend speech reactivity, and sport speech reactivity) by converting each participant's TPR and CO values into z-scores and summing them. We assigned TPR a weight of −1 and CO a weight of +1, such that a larger value corresponds to greater challenge for reactivity terms. TPR and CO are best viewed as two related measures of the same underlying SAM vs. PAC activation, so this process should have the effect of creating a single measure out of two. Although this yields only relative challenge and threat differences—losing the absolute meaning of TPR and CO—it does allow us to assess the pattern of cardiovascular reactivity in a single analysis. The absolute values of correlations between the three index scores and their component TPR and CO values ranged from .93 to .96, indicating that the index calculation achieved its desired effect.

In the regression for the challenge and threat index, the addition of Step 2 accounted for a significant portion of variance in runs created, step $R^2 = .11$, $p < .05$, such that challenge during the sport speech was associated

[3] Attesting to the hypothesized specificity of our cardiovascular indexes, measures of task engagement (HR and VC) failed to predict performance, as did other cardiovascular measures that are commonly interpreted as reflecting "generalized arousal" (i.e., systolic blood pressure, diastolic blood pressure, and mean arterial pressure).

[4] Although the use of change scores (of which reactivity is one example) is sometimes discouraged on psychometric grounds (e.g., Cronbach & Furby, 1970), their use is common in psychophysiological work. In the context of assessing task reactivity from baseline, Llabre, Spitzer, Saab, Ironson, and Schneiderman (1991) concluded that the reliability of change scores typically is comparable to or exceeds that of residualized change scores, calculated by regressing task levels on baseline levels and then subtracting the generated predicted values from observed values. Perhaps unlike some other potential applications, changes from the baseline "zero point" do have meaning for our purposes in that we typically examine both relative differences in challenge vs. threat (as is done in this paper) and—when using a factorial design—absolute levels of challenge vs. threat by testing reactivity against zero. However, because of the possibility that change scores can produce artifactual results due to correlations between baseline levels and magnitude of change, we adopted a conservative approach: we controlled for baseline levels when using reactivity to predict athletic performance. This should account for any confounding effect that magnitude of baseline level has on magnitude of reactivity.

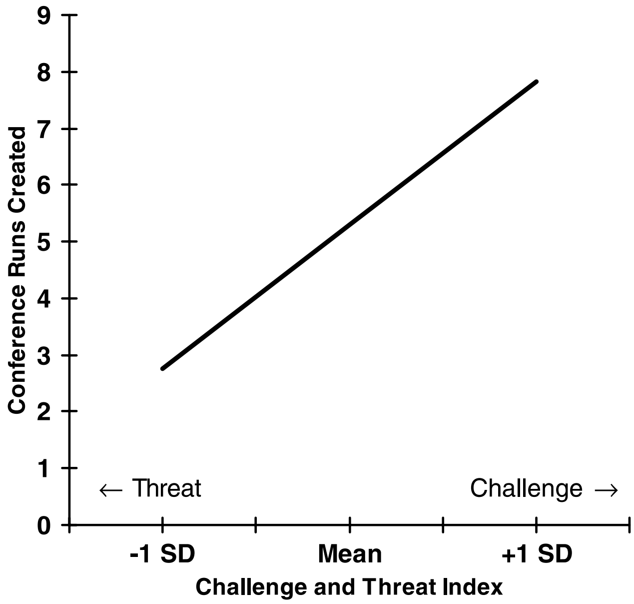

Fig. 1. Challenge and threat reactivity during the sports-related speech as a predictor of subsequent athletic performance, where a higher index value indicates greater relative challenge. One standard deviation represents 1.88 index units.

with more runs created during the subsequent season ($b = 1.35$, $\beta = .46$; see Fig. 1).[5,6]

Discussion

As hypothesized, our results indicated that after controlling for team membership, baseline values, and responses to speech-giving in general, athletes who exhibited challenge while imagining and speaking about playing their sport performed better during the subsequent season than did athletes who exhibited threat. A substantial percentage of the total variance in performance was explained statistically by athletes' motivational states. These findings are important theoretically because they demonstrate the predictive validity of the BPS model of challenge and threat as indexed by patterns of cardiovascular responses in a real-world context. Until this study, performance differences between challenge and threat had been limited to the laboratory and had been concurrent with measurement of the cardiovascular responses.

We can speculate that better players were more challenged during the sport-relevant speech task and poorer players were more threatened because of knowledge of their own abilities. In particular, it may be the case that good players simply knew that they were good before the season began. Due to their greater confidence, good players were more likely than others to exhibit challenge in the laboratory while imagining playing their sport. During the subsequent season, good players may have outperformed others because of their athletic ability.

However, mere knowledge of one's ability may not completely explain our findings. In college sports, personnel turnover occurs as older players exhaust their eligibility to play and younger players develop and compete for starting positions. Our sample exhibited such turnover: of the 27 batters with usable data who participated in the study, 17 had statistics from the previous year. Among those 17, batting statistics from the previous year correlated .56 with the statistics from the season used in this study. Although a relationship clearly exists between the two seasons, nearly three-quarters of the variance in the target season's statistics cannot be accounted for by statistics from the previous season, even among returning players, indicating that it would have been difficult for the athletes in our sample to know with great certainty how well they would perform relative to their teammates in the upcoming season.

Unfortunately, the sample size in this study was too small to allow for meaningful mediational analyses that would better test this suggestion. However, regardless of what caused challenge vs. threat during the sport speech (knowledge of previous ability or tendency to experience that state during game performance)—which has not been resolved in this study—the fact remains that physiological challenge and threat responses exhibited in the laboratory predicted athletic performance during the subsequent season.

It is possible that challenge and threat play a causal role in performance differences, although we can only speculate about the exact nature of such a role. During threat, individuals may divert attentional resources away from the task at hand and towards the environment or

[5] We made an a priori decision to use runs created during conference games as the measure of athletic performance, but other measures yielded similar results, such that responses consistent with greater challenge during the sport speech tended to be associated with better performance. For conference batting average: Step 2 TPR $p < .07$, CO $p < .17$, and challenge/threat index $p < .08$. For full-season runs created: Step 2 TPR $p = .05$, CO $p < .14$, and challenge/threat index $p < .06$.

[6] The effect of control (friend) speech reactivity in Step 1 approached significance for TPR ($p = .06$, $b = .016$, $\beta = .33$, $sr^2 = .10$), such that lower TPR—consistent with greater challenge—was associated with *worse* performance. The effect did not approach significance for CO or the challenge/threat index, but the direction for both was consistent with TPR. The effect of control speech reactivity in Step 2 was significant for TPR ($p < .01$, $b = .025$, $\beta = .51$, $sr^2 = .19$) and the challenge/threat index ($p < .05$, $b = -1.43$, $\beta = -.48$, $sr^2 = .15$), but not for CO ($p = .11$, $b = -1.94$, $\beta = -.37$, $sr^2 = .08$). For all three measures, greater challenge was again associated with worse performance. This effect is difficult to interpret because all participants knew the study was somehow related to their status as college athletes. For example, it may be the case that participants for whom discussing a sport-irrelevant topic was a "relief" in this context (yielding challenge) were either less skilled than others or less comfortable in high-pressure game situations, both of which could result in relatively lower performance quality.

themselves. Some indirect support exists for this notion. In one study, Hunter (2001) induced either challenge or threat, immediately after which participants completed a lexical decision task. During subsequent free recall, threatened participants were more likely to generate words associated with danger, consistent with the notion that threat may cause heightened vigilance, perhaps at the expense of concentrating on the task and maximizing performance. In a different series of studies not utilizing challenge and threat indexes, Baumeister (1984) found that instructing participants to focus on themselves while performing a manual dexterity task caused them to perform worse than participants who were instructed to focus on a component of the task itself. Hence, threat may result in increased self-focus, thus mediating performance differences between challenge and threat.

The present investigation has implications for personnel selection, especially in sports, with the proviso that this is a single study with a small sample. It may be possible to identify individuals who have "heart" or "mental toughness," who are more likely to be challenged and thus perform well in critical situations in a given performance domain. Although a better understanding of underlying causal mechanisms is essential, we believe the findings presented here suggest that physical skills, knowledge, and ability alone do not provide the whole story in determining success or failure in athletic performance. Instead, motivational states experienced during that performance may also play a key role. By applying the challenge and threat model and methodology, the intangibles in performance—including sports performance—might become more assessable.

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