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4 The prediction of thriving in elite sport: A prospective examination of the role of psychological
5 need satisfaction, challenge appraisal, and salivary biomarkers

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29 Abstract

30 *Objectives.* To examine (i) whether levels of, and changes in, athletes' basic psychological need
31 satisfaction (BPNS) and challenge appraisals predicted in-match thriving; and (ii) if salivary
32 biomarkers could be defined that were related to thriving.

33 *Design.* Prospective study design.

34 *Method.* Fifty-one elite male hockey players ($M_{\text{age}} = 24.94$ years, $SD_{\text{age}} = 4.73$) completed
35 questionnaires measuring their BPNS and challenge appraisals on seven consecutive days prior to a
36 competitive match, as well as providing saliva samples immediately on waking, and then + 0.5, + 3,
37 and + 5.25 hours on the day of the match. Saliva was assayed for catabolic (i.e., cortisol) and anabolic
38 (i.e., dehydroepiandrosterone [DHEA]) hormones. In-match thriving was assessed retrospectively
39 using measures of subjective performance and well-being.

40 *Results.* Latent growth curve modelling showed pre-match levels of BPNS and challenge appraisals to
41 positively predict thriving. Although not statistically significant, small and moderate negative
42 associations were found for thriving with cortisol concentration (+ 5.25 hours sample) and total
43 cortisol exposure across the morning of the match, respectively. DHEA concentration shared a small
44 positive, yet non-significant, association with thriving.

45 *Conclusions.* Athletes' pre-match levels of BPNS and challenge appraisal predict in-match thriving;
46 thus, offering potential mechanisms through which both high-level performance and the experience of
47 well-being can be facilitated. Furthermore, associations suggest that total cortisol exposure across the
48 morning of the match, and cortisol and DHEA levels in pre-match samples may offer sport science
49 and sports medicine practitioners potential biomarkers for thriving. Future research is required to
50 substantiate this initial finding.

51 *Keywords:* cortisol, dehydroepiandrosterone, Monte Carlo power calculations, performance,
52 thrive, well-being

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Introduction

With growing calls in elite sport to ensure the protection and promotion of athlete well-being whilst in pursuit of optimal performance, it is essential that research establishes the factors that can predict the joint occurrence of these outcomes. A construct that may assist in this pursuit is *thriving*. Individuals who are thriving have been described as experiencing full or holistic functioning^{1,2} and, within sport, this experience has been characterized by the simultaneous display of high-level performance and the experience of well-being.^{3,4} More specifically, thriving performers have been identified as those who report highest levels across subjective performance (via performance satisfaction), eudaimonic well-being (via subjective vitality), and hedonic well-being (via positive affect) dimensions.³

Literature on thriving in sport has begun to identify the psychosocial variables important for understanding why some performers thrive whereas others do not. For example, exhibiting a readiness for challenge was shown to enable thriving during a geographic transition,⁵ and operating within an integrated, inclusive, and trusting environment was suggested to facilitate thriving within a professional team sport.⁶ To explain these associations and understand *how* these factors influence thriving, it is necessary to examine the mechanistic variables at play (i.e., the proximal determinants of thriving). Two candidate variables previously suggested to determine thriving are basic psychological need satisfaction (BPNS) and challenge appraisal.^{1,2} BPNS describes the degree to which individuals experience satisfaction of the basic psychological needs for autonomy (i.e., need for volitional, congruent, and integrated functioning), competence (i.e., need to feel effectance and mastery), and relatedness (i.e., need to feel socially connected and cared for).² Scholars have argued that the satisfaction of these three needs reflects human thriving in the deepest sense and therefore such satisfactions predict indicators reflective of wellness and optimal functioning.² Challenge appraisal describes a type of judgment made by humans when faced with a situation that has relevance for personal well-being.⁷ More specifically, challenge appraisals occur when the personal significance of the stressor is in proportion to the available coping resources, resulting in the belief that gain or growth may occur.⁸ Perceiving a situation as a challenge is, therefore, likely to encourage engagement and create opportunities for positive change.⁹ Within a sport setting, Brown et al.³ have

82 shown support for a positive, predictive relationship between BPNS, challenge appraisal, and
83 membership to a thriving profile. Yet, these findings were limited by participants completing, at a
84 one-off time-point, measures of the study variables retrospectively after their sporting encounters.
85 Thus, when using this approach, it was possible that the performers' assessments of pre-match
86 variables were distorted by the match outcome. To advance this research, it is therefore necessary to
87 conduct discrete assessments of pre-match variables and subsequent outcomes.

88 Both BPNS² and challenge appraisal⁷ are dynamic and fluctuate over time. Indeed, within-
89 person daily fluctuations in BPNS and challenge appraisal have been found to predict pre- post-
90 practice changes in well-being¹⁰ and daily affective states,¹¹ respectively. Within this work, changes
91 have typically been considered on a cyclical basis (i.e., from day-to-day) with limited consideration
92 given to how state-based perceptions alter towards a focal event (e.g., an important match). The
93 absence of these prospective studies tells us little about how levels of BPNS and challenge appraisal
94 fluctuate in advance of a match (e.g., increase linearly, oscillate between high and low levels), and
95 whether the nature of such changes has an impact on 'in-match' outcomes such as thriving. Within the
96 context of the present study, it is anticipated that there will be changes in players' BPNS and
97 challenge appraisal contingent on their daily involvements with their sport, and the proximity of the
98 match. For example, training sessions occurring in the days preceding the match were anticipated to
99 strengthen feelings of closeness between players, and to provide an opportunity for individuals to
100 participate in their sport willingly and demonstrate proficiency in their skillset. Furthermore, levels of
101 BPNS are likely to increase in the days closest to a match as a player mentally prepares themselves
102 for their upcoming sporting involvement (e.g., using self-talk to enhance perceived competence).¹²
103 Levels of challenge appraisal are also anticipated to increase as the match approaches given the
104 motives and personality of elite athletes. To elaborate, previous research with elite athletes has
105 documented their insatiable desire to compete at the highest-level given the opportunity it affords
106 them to improve and increase their perceived standing in sport.¹³ Irrespective of whether the players
107 participate for personal development or competitive reasons, both options would present the match as
108 an opportunity for growth, and it is likely that players' perceptions of their sport as a challenge will
109 become more intense/apparent as the match approaches and expectations escalate.

110 In addition to the use of psychosocial variables to predict thriving, researchers have suggested
111 that a physiological mechanism may exist for thriving and that physical thriving could be investigated
112 via an individual's hormonal response to a stressful situation.^{14,15} More specifically, thriving is
113 hypothesized to occur when a greater amount of anabolic hormones (i.e., those involved in restorative
114 processes), rather than catabolic hormones (i.e., those involved in protective processes), are released
115 in a stress response.¹⁴ To examine the effect of the simultaneous secretion of anabolic and catabolic
116 hormones, researchers have derived a ratio of both hormone types, known as anabolic balance.¹⁵ Two
117 hormones that have been used to examine these effects are dehydroepiandrosterone (DHEA; anabolic)
118 and cortisol (catabolic). DHEA concentration increases significantly in response to acute stress¹⁶ and
119 has been suggested to have wide-ranging functions including positive effects on immune function and
120 well-being.¹⁷ Secretion of cortisol also increases acutely in anticipation of a threat and is thought to
121 act by diverting energy away from non-essential bodily functions and redirecting resources.¹⁸ In
122 addition to considering the ratio in which these hormones are released, Epel et al.¹⁴ have argued that
123 the dampening of the acute cortisol response to a stressor may be associated with thriving, as a
124 reduced response would demonstrate an individual's habituation and a perceived ability to cope with
125 the demand. Despite these suggestions, to date, only one study exists that has examined anabolic
126 balance in sport¹⁹ and no known studies have tested the physiological mechanism of thriving in
127 performance settings.

128 Addressing the aforementioned gaps in the literature, this study sought to examine (i) whether
129 levels of, and changes in, athletes' BPNS and challenge appraisals predicted in-match thriving and (ii)
130 if salivary biomarkers could be defined that were related to thriving. It was hypothesized that (i)
131 higher levels of, and increases in, BPNS and challenge appraisal would positively predict in-match
132 thriving; (ii) DHEA concentration and the ratio of DHEA:cortisol (i.e., anabolic balance) immediately
133 before the match would be positively related to in-match thriving; and (iii) total cortisol exposure
134 across the morning and cortisol concentration immediately before the match would be negatively
135 related to in-match thriving.

136 **Methods**

137 Following institutional ethical approval (EP 14/15 200), elite male field hockey teams were

138 identified based on their involvement in international or national level competition. The head coaches
139 and players from three teams provided informed consent, and the coaches then helped to select a
140 match prior to which it was logistically feasible to collect data. Recruiting participants from three
141 teams was deemed adequate for the present study given that (i) this represented over a fifth of the
142 teams competing at this level within the geographic vicinity of the research site; (ii) the logistical
143 complexity inherent in conducting this interdisciplinary study; and (iii) the lack of physical and
144 financial resources available to conduct the work in other sites across the country. Fifty-one players
145 ($M_{\text{age}} = 24.94$ years, $SD_{\text{age}} = 4.73$) took part, with an average of 16.89 ($SD = 5.92$) years' experience
146 playing hockey. All playing positions were represented.

147 Six days prior to the match, participants were e-mailed a hyperlink to a multi-section
148 questionnaire. Participants were asked to complete the questionnaire online on that and each of the
149 next five evenings, and in paper format on arrival at the match. The questionnaire contained brief,
150 modified scales to assess BPNS and challenge appraisal, and the participants completed the scales in
151 relation to how they felt *at that time* about their hockey involvement. BPNS was assessed using three
152 items from the Basic Needs Satisfaction in Sport Scale (BNSSS),²⁰ with the items selected via item
153 response theory analysis conducted on responses previously collected from 535 sport performers.³
154 The median α for the composite score for BPNS was .79. Challenge appraisal was assessed using the
155 two-item version of McGregor and Elliot's²¹ task construal measure (median r across time-points =
156 .90).

157 At a training session occurring > 48 hours prior to the match, participants were provided four
158 saliva collection tubes labelled with the match day sampling times. Saliva was collected by the
159 passive drool technique²² (3-minute collection) into pre-weighed centrifuge tubes (FisherbrandTM;
160 Fisher Scientific, Loughborough, UK), and participants were asked not to eat, drink, or brush their
161 teeth in the hour before sampling.²³ Saliva samples were provided by participants on the day of the
162 match immediately on waking, and then + 0.5 hours ($M = 00:29$, $SD = 00:01$), + 3 hours ($M = 02:57$,
163 $SD = 00:23$), and + 5.25 hours ($M = 05:18$, $SD = 00:35$) to partly capture the diurnal rhythm of
164 cortisol release and, in particular, the cortisol awakening response.^{24, 25} Participants were asked to
165 write down the exact time at which samples were provided and, where possible, waking time was

166 verified using data collected from a waist-worn ActiGraph GT3X+ (ActiGraph LLC, Pensacola, FL)
167 triaxial accelerometer. The + 5.25 hours sample coincided with completion of the pre-match
168 questionnaire (collected immediately before commencing match warm-ups). Samples were collected
169 from participants prior to the match and stored at 4 °C until being processed within the following three
170 days. During processing tubes were centrifuged at $2000 \times g$ for 10 minutes to remove particulate
171 matter, and the saliva was aliquoted into micro-centrifuge tubes (Eppendorf, Hamburg, Germany) and
172 stored at -20 °C until assay. Salivary cortisol and DHEA levels were analyzed in duplicate using
173 commercially available ELISAs according to manufacturer instructions (Salimetrics, Newmarket,
174 UK). Absorbance values were measured using a microplate reader (SPECTROstar Nano; BMG
175 Labtech, Ortenberg, Germany). To provide a robust assessment of total cortisol exposure across the
176 morning of the match, cortisol levels in the four samples were used to calculate the area under the
177 curve using the trapezoid method relative to ground. The ratio of DHEA:cortisol was calculated using
178 data from the + 5.25 hours sample to provide a pre-match assessment of anabolic balance.

179 Post-match, participants completed a questionnaire to assess their experience of thriving. In
180 accordance with literature,³ thriving was assessed by measuring subjective performance, positive
181 affect, and subjective vitality. Specifically, participants were asked to rate their satisfaction with their
182 performance in the match.²⁶ Positive affect was assessed using the International Positive and Negative
183 Affect Schedule Short Form (I-PANAS-SF),²⁷ with participants requested to report the regularity with
184 which they experienced five emotional descriptors during the match ($\alpha = .71$). Finally, participants
185 completed an abbreviated version of the Subjective Vitality Scale (SVS),²⁸ which required them to
186 respond to how accurate four statements were in relation to their match experiences ($\alpha = .91$).

187 Latent growth curve modelling (LGM) was used to examine changes in BPNS and challenge
188 appraisal in the week leading up to the match, and the effect these changes had on in-match thriving.
189 Time was centered on match day and the intercept factor, therefore, represented the level of the
190 variables reported immediately pre-match. The first step in the analysis was to ascertain the best
191 fitting growth model for each of the variables using intercept-only, linear, and quadratic growth
192 models. Models were compared using the Akaike's Information Criterion (AIC) and the Bayesian
193 Information Criterion (BIC), with smaller AIC and BIC values indicating a better fitting model.²⁹

194 Where a difference of < 2 BIC was identified between models, the difference was not considered
195 worthy of mention, and the model with the lower AIC was selected.³⁰

196 The second step in the analysis was to determine whether the latent growth factors for BPNS
197 and challenge appraisal predicted in-match thriving. Thriving scores were computed from a
198 measurement model (see Supplementary Material) and then modelled as a manifest distal outcome
199 variable in two growth models (i.e., one for BPNS and one for challenge appraisal; see Supplementary
200 Material). Paths between the intercept and slope growth factors and thriving were tested for statistical
201 significance. Model fit was determined using the Comparative Fit Index (CFI), the Tucker Lewis
202 Index (TLI), and the Root Mean Square Error of Approximation (RMSEA). Acceptable values were
203 close to or above .90 for CFI and .95 for TLI, and close to or below .08 for RMSEA; however, it is
204 commonly acknowledged that latent growth models display poor fit against conventional criteria.³¹
205 The relationships between the salivary variables and thriving were determined by correlating thriving
206 with each variable individually. The decision to examine the correlations individually was made as
207 portions of the data were included in multiple variables (e.g., total cortisol exposure and cortisol
208 concentration). Pearson correlations of .1, .3, and .5 were interpreted as small, medium, and large,
209 respectively.³² LGM and correlation analyses were conducted in Mplus 8.2³³ using the Full
210 Information Maximum Likelihood Robust (MLR) estimation to account for any missing data and non-
211 normality. To test the plausibility of the effect sizes derived from our design and analytical approach,
212 we conducted post hoc power analyses using Monte Carlo^{34, 35} studies against the threshold for
213 desirable power of 0.80; example inputs from these studies can be viewed in the Supplementary
214 Material. In addition to the main analysis, changes in cortisol concentration across the four samples
215 were analyzed using repeated measures ANOVA in SPSS 25.³⁶

216 Results

217 Of the 51 participants who commenced participation in the study, seven were excluded from
218 the final data set because they either did not play in the match ($n = 5$) or they did not complete the
219 post-match questionnaire ($n = 2$). Descriptive statistics for the remaining 44 participants are presented
220 in Table 1. Daily survey completion rates across the sample ranged from 66-100%, with individual
221 participants providing an average of five responses. Results from the LGM showed the intercept-only

222 growth model to provide the best fit to the BPNS data (Table 2). The BPNS intercept mean was
223 significant suggesting that levels of need satisfaction immediately pre-match were significantly
224 different from zero ($M_{\text{intercept}} = 6.22$, $p < 0.001$, power = 1.00). Furthermore, significant variability was
225 found in these pre-match BPNS scores ($Var_{\text{intercept}} = 0.35$, $p = 0.006$, power = 1.00), indicating
226 between-person differences prior to the match. When thriving was added as a distal outcome to the
227 intercept-only growth model, a significant positive regression path was found between the intercept
228 growth factor and thriving ($\hat{\beta} = 0.73$, $p = 0.034$, $\hat{\beta}^{\text{standardized}} = 0.36$, $R^2 = 13\%$, power = 0.71),
229 showing that higher pre-match BPNS was associated with higher levels of in-match thriving.

230 A linear growth model was identified as the best fitting model for challenge appraisal (Table
231 2). The challenge appraisal intercept mean was significant suggesting that levels of challenge
232 appraisal immediately pre-match were significantly different from zero ($M_{\text{intercept}} = 6.33$, $p < 0.001$,
233 power = 1.00). Furthermore, significant variability was found in pre-match challenge appraisal
234 ($Var_{\text{intercept}} = 0.48$, $p = 0.005$, power = 1.00), indicating between-person differences pre-match. The
235 slope growth factor showed a significant increase in challenge appraisal as the match approached
236 ($M_{\text{slope}} = 0.03$, $p = 0.040$, power = 0.61) and since the slope variance was not significant ($Var_{\text{slope}} =$
237 0.00 , $p = 0.160$, power = 0.35), this suggests that all participants followed a similar trajectory around
238 the mean growth curve. When thriving was added as a distal outcome to the linear growth model, a
239 significant positive regression path was found between participants' pre-match challenge appraisal
240 and in-match thriving ($\hat{\beta} = 0.58$, $p = 0.018$, $\hat{\beta}^{\text{standardized}} = 0.33$, power = 0.48), indicating that
241 participants who reported greater levels of challenge appraisal were more likely to thrive in the match.
242 A negative, non-significant regression path was found between the rate of change in challenge
243 appraisal and thriving ($\hat{\beta} = -3.23$, $p = 0.469$, $\hat{\beta}^{\text{standardized}} = -0.15$, $R^2 = 11\%$, power = 0.06),
244 suggesting that changes in challenge appraisal in the week before the match were unrelated to in-
245 match thriving.

246 The salivary cortisol and DHEA analyses were conducted with a sample subgroup.
247 Specifically, the analyses focused on participants ($n = 21$) whose match was played in the early
248 afternoon; the remaining participants were excluded as their match took place in the evening where

249 levels of cortisol and DHEA would be lower due to the diurnal rhythm of the hormones. The pre-
250 match salivary cortisol values are displayed in Figure 1. Results from repeated measures ANOVA
251 showed that cortisol levels were significantly different over time, $F(3, 60) = 8.85, p < .001, \omega^2 = 0.12$.
252 Bivariate correlations revealed a small negative non-significant correlation between +5.25 hours
253 cortisol concentration and thriving ($r = -.22, p = 0.355, \text{power} = 0.17$) and a moderate negative non-
254 significant correlation between total cortisol exposure across the morning of the match and thriving (r
255 $= -.32, p = 0.169, \text{power} = 0.31$). Furthermore, a small positive non-significant correlation was
256 observed between + 5.25 hours DHEA concentration and thriving ($r = .28, p = 0.145, \text{power} = 0.25$).
257 Finally, a non-significant relationship was found between the ratio of DHEA:cortisol and thriving in
258 the + 5.25 hours sample ($r = .00, p = 0.991, \text{power} = 0.07$).

259 Discussion

260 This study examined whether levels of, and changes in, perceptions of BPNS and challenge
261 appraisal predicted in-match thriving in elite athletes, and if salivary biomarkers related to thriving
262 could be defined. BPNS and challenge appraisals reported immediately pre-match were shown to
263 positively predict in-match thriving, with total cortisol exposure across the morning of the match, and
264 cortisol and DHEA levels measured immediately pre-match shown to have small and moderate, albeit
265 non-significant, associations with thriving.

266 The results show that athletes' daily perceptions of BPNS were stable in the week before the
267 match, with levels of BPNS reported immediately pre-match positively predicting in-match thriving.
268 Although scores of certain BPNS measures have been shown to support stability over-time,³⁷ the
269 stability reported in the present study is in contrast to previous research reporting daily fluctuations in
270 autonomy, competence, and relatedness in athletic groups³⁸ and the increase in BPNS that we
271 hypothesized. Drawing from previous sport-based research that has reported moderate levels of
272 stability for perceptions of coach autonomy support behaviors,³⁹ it is plausible that the stable levels of
273 BPNS reported by athletes in the present study are indicative of consistency in coaching style and
274 coach-player interactions, irrespective of the nature of daily interactions (i.e., in-person vs. remote)
275 and the proximity of important matches. Despite previous theoretical suggestions that BPNS is a
276 thriving prerequisite² and empirical evidence demonstrating a relationship in sport performers,³ no

277 prospective studies had been conducted to verify this effect. Therefore, finding a significant prediction
278 through prospective measurements represents a substantial advancement in the evidence for the role
279 of BPNS on thriving. In so doing, this finding provides further empirical support for theoretical
280 reasoning within SDT that the satisfaction of the three basic psychological needs reflects human
281 thriving in the deepest sense.²

282 To our knowledge, this study also represents the first attempt to prospectively examine
283 athletes' challenge appraisals in the week before a match. Thus, these data are the first to show that
284 perceptions of challenge increase as a match approaches, with levels reported immediately pre-match
285 positively predicting thriving. Finding increases in challenge appraisal as the match approached
286 supported our hypothesis that players' thoughts about their sport representing an opportunity for
287 growth would become more intense/apparent as it became closer. Interestingly, the absence of
288 variability in this pattern across participants suggested that all players experienced a similar
289 'anticipatory rise' for the upcoming match. Notwithstanding these changes in challenge appraisals
290 over the week, the rate of change was not predictive of thriving, suggesting that it is not how levels of
291 challenge alter that impact whether athletes thrive; rather, it is the level of challenge reported
292 immediately pre-match that is important for in-match thriving. Challenge appraisals have previously
293 been found to directly elicit facilitative outcomes in sport performances,⁴⁰ and to indirectly impact
294 performance and well-being through task engagement and effective coping.⁴¹ Therefore, within the
295 present study, players reported higher levels of challenge appraisal may have approached and engaged
296 with the demands of the encounter in a facilitative manner, effectively overcame demands, and,
297 ultimately, thrived. Whereas those who reported lower levels of challenge appraisal may have been
298 more hesitant in their responses to the demands and have only managed or succumbed to them.

299 Previous research has suggested that thriving may manifest physiologically through an
300 individual's hormonal response to a demanding situation.¹⁴ The present study was the first to examine
301 this suggestion in a performance setting and to hypothesize that pre-match salivary cortisol reactivity
302 and salivary DHEA were potential biomarkers for thriving in sport. Although not statistically
303 significant, the respective small and moderate negative correlations found between cortisol
304 concentration and total cortisol exposure with thriving support Epel et al.'s¹⁴ suggestion that a

305 dampened acute cortisol response to stress would be associated with thriving. Given that cortisol is
306 released in response to stressors,¹⁸ a smaller cortisol response in players who went on to thrive could
307 be indicative of those individuals perceiving lower stressor dimensions or implementing more
308 adaptive response mechanisms on the morning of the match. Notwithstanding this interpretation, it is
309 important to acknowledge that exposure to chronic stress can also lead to a blunted cortisol
310 response,⁴² so it would be important in future work to further examine how ongoing stress exposure
311 may impact these acute responses. Players' DHEA levels collected immediately pre-match had a
312 small positive correlation with subsequent thriving supporting the proposed salutary effect of DHEA
313 on well-being.¹⁷ Although the mechanisms underlying the effects of DHEA remain unknown,¹⁷ the
314 results of this study add to the extant literature by demonstrating possible positive effects in athletic
315 men when exposed to acute stress (i.e., pre-match demands). In contrast to considering salivary
316 cortisol and DHEA independently, anabolic balance (i.e., the ratio of salivary DHEA:cortisol in the +
317 5.25 hours sample) showed no association with thriving; this result challenges previous suggestions of
318 a role of anabolic balance in thriving.¹⁴ The inconsistent findings for the relationships of DHEA
319 concentration and DHEA:cortisol ratio with thriving may suggest that different processes exist for
320 these salivary measures in response to stress.

321 Despite the notable strengths of this study in terms of its originality (i.e., the first prospective
322 study of thriving in sport to examine potential salivary biomarkers for thriving) and significance for
323 practice (i.e., informing the promotion of performance and well-being in sport), the applied context
324 within which the study was conducted raised some limitations with regards to the statistical power in
325 some analyses. First, the asynchronous timing of one of the fixtures meant that it was not possible to
326 include data from all participants in the analysis of the salivary variables. As a result, and based on the
327 reported effect sizes, power analyses indicated that the chances of finding statistically significant
328 effects for the salivary analyses—assuming that they existed—ranged between 7 and 31%. Second,
329 despite recruiting players from a significant proportion of the elite teams available for the study, some
330 analyses in the more complex LGM lacked statistical power suggesting that null hypotheses may have
331 been incorrectly accepted for some results. Given that power within LGMs varies contingent not just
332 on the sample size, but also due to missing data, parameter values, and the number of time points,⁴³

333 the absence of known parameter estimates and missing data patterns meant that it was not possible to
334 conduct an a priori power calculation for this study. Researchers are encouraged to use the estimates
335 and response patterns reported herein to inform sample size calculations and improve power in future
336 work and, in so doing, reduce the risk of false positive and false negative findings. Third, awakening
337 was not controlled by the researchers to encourage compliance and allow the players to follow their
338 typical match-day routine. Instead, accelerometry was used to record sleep times and verify the time
339 of awakening. Not all participants adhered to wearing the accelerometer due to experiencing
340 discomfort and subsequent disturbed sleep. Thus, it was not possible to verify waking time for all
341 participants. Fourth, it is possible that the relationships between the variables recorded pre-match and
342 thriving assessment collected post-match were influenced by in-match events and experiences (e.g.,
343 confrontation with a teammate or coach). Although it is not feasible to collect self-reported measures
344 of such factors during a competitive match in a continuous sport like hockey, sports with regular
345 breaks in play (e.g., tennis and golf) may afford researchers with better opportunities to capture these
346 experiences through brief, self-report scales. Fifth, the LGM showed that basic psychological need
347 satisfaction and challenge appraisal explained 13% and 11% of the variance in thriving, respectively.
348 It is therefore important that future research also considers the predictive effects of additional inter-
349 individual variables as well as pertinent interpersonal factors.

350 **Conclusion**

351 This study found that levels of BPNS and challenge appraisals reported immediately before a
352 sporting encounter positively predicted in-match thriving. This prospective work advances knowledge
353 gleaned from cross-sectional studies, with findings offering coaches and sport science and sports
354 medicine practitioners potential mechanisms through which they can facilitate both high-level
355 performance and the experience of well-being. The research also represented the first examination of
356 salivary biomarkers for thriving, with total cortisol exposure across the morning of the match, and
357 cortisol and DHEA levels measured immediately pre-match representing potential early detection
358 mechanisms for subsequent athlete thriving.

359 **Practical Implications**

- 360 • Promoting elite athletes' feelings of autonomy, competence, and relatedness, and developing
361 their interpretations of sport as an opportunity for growth, may enable them to experience
362 enhanced in-match performance and well-being.
- 363 • The measurement of salivary cortisol and dehydroepiandrosterone pre-match may offer
364 practitioners prior indication of whether players are expected to thrive.

365

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Table 1. *Descriptive Statistics for Psychological Process Variables, Biomarkers Variables, and Thriving Indicators*

Variable	6 days		5 days		4 days		3 days		2 days		1 day		Pre-match		Post-match		
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Psychosocial Process Variables																	
BPNS (1-7)	6.32	0.63	6.22	0.78	6.01	0.78	6.14	0.75	6.22	0.52	6.19	0.69	6.27	0.62			
Challenge appraisal (1-7)	6.10	0.74	6.19	0.76	6.08	0.93	6.18	0.90	6.33	0.66	6.30	0.76	6.31	0.73			
Salivary Biomarker Variables ($\mu\text{g/dL}$)																	
Pre-match cortisol (+ 5.25 sample)														0.31	0.17		
Pre-match DHEA (+ 5.25 sample)														0.02	0.01		
Total cortisol exposure														94.82	31.36		
Thriving Indicators																	
Subjective performance (0 – 10)																5.71	1.93
Subjective vitality (1-6)																4.86	0.75
Positive affect (1-5)																4.13	0.52

Table 2. *Latent Growth Model Fit Statistics*

Model	Fit Indices				
	AIC	BIC	CFI	TLI	RMSEA [90% CI]
Basic Psychological Need Satisfaction					
Intercept-only	237.78	253.84	0.94	0.95	.13 [.06, .19]
Linear ^a	242.69	264.10	0.94	0.94	.14 [.08, .21]
Challenge Appraisal					
Intercept-only	337.46	353.52	0.96	0.97	.09 [.00, .16]
Linear	333.14	354.55	0.99	0.99	.06 [.00, .14]
Quadratic	331.56	360.11	1.00	1.00	.00 [.00, .11]

Note. AIC = Akaike's information criterion; BIC = Bayesian information criterion; CFI = comparative fit index; TLI = Tucker-Lewis index; RMSEA = root mean square error of approximation; CI = confidence interval.

^aThe covariance matrix of the latent growth factors was not a proper covariance matrix. The problem was associated with the growth factor *Slope*. The variance of this variable is very small and not statistically significant ($Var_s < .001$, $z = 0.09$, $p = .815$). In addition, the correlation between the intercept and linear growth factors was estimated to be -1.14, which is an inadmissible value for a correlation coefficient. Thus, the model fit statistics and model results may not be accurate.

Figure Captions

Fig 1 Mean concentration of salivary cortisol measured at each time-point. Error bars = standard error of mean.

Author Accepted Version