Columbia University

Mental Fatigue's Impact on Team Performance:

An Analysis of the Columbia Division I Field Hockey Team

Abstract:

Physical fatigue is a well-studied determinant of athletic performance. Proper recovery from training can increase athletic performance, while poor recovery allows this fatigue to inhibit performance. Researchers have given mental fatigue less attention in this domain. This paper argues that mental fatigue has significant adverse effects on athletic performance. This paper finds that an increase in a team's mental fatigue decreases the team's probability of winning the subsequent game and decreases the team's ability to execute mentally demanding skills. Further research must be done to understand how we can help athletes reach peak performance through both physical *and* mental recovery.

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For years, researchers have analyzed how physical fatigue impacts athletic performance. Richard Budgett (1998) was the first to coin the "overtraining syndrome." He explained overtraining as a result of hard physical workouts without proper recovery. As evident below (see Figure 1), he found that "initial hard training causes underperformance but if recovery is allowed, there is supercompensation and improvement in performance" (Budgett, 1998, p. 1). However, when athletes fail to recover properly, they may suffer from the overtraining syndrome, where physical fatigue leads to a decline in performance (Budgett, 1998).

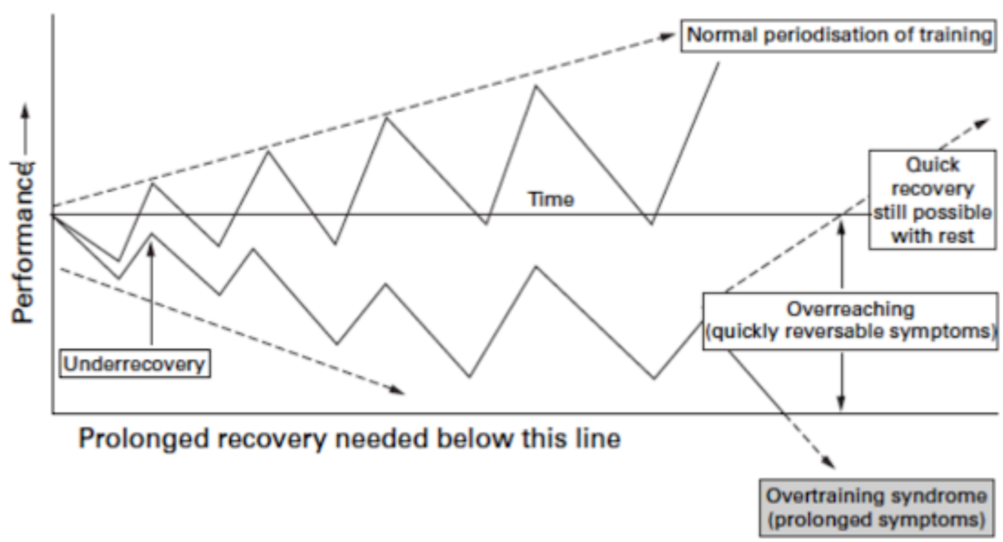

Figure 1: Under-Recovery from Physical Fatigue Leads to a Decline in Athletic Performance

Today, nearly 20 years later, most collegiate and professional sports teams have acknowledged the overtraining syndrome and now have vast resources and skilled employees to avoid its negative ramifications. Although we seem to have addressed this physical component, the conversation surrounding proper recovery may have overlooked an additional variable.

While research has focused primarily on physical fatigue, it has not addressed mental fatigue to the extent it deserves. Could mental fatigue lead to a similar decline in athletic performance? In other words, could athletes not only under-recover physically, but also mentally. If so, would this mental under-recovery deteriorate overall athletic performance?

Marcora et al. (2009) analyzed this effect of mental fatigue on athletic performance. They found that mentally fatigued cyclists reached their maximal level of perceived exertion significantly earlier than the control group. The experimental group disengaged from the cycling task earlier than the control condition. Thus, they found that mental fatigue decreases an individual's tolerance to exercise (Marcora et al., 2009).

In a later study, Marcora et al. (2016) evaluated mental fatigue on soccer performance. They found that mentally fatigued soccer players had a significant decline in shot speed and in accuracy. They also dropped out of the running test earlier than the control group—another example of how mental fatigue decreases exercise tolerance.

To address possible remedies to mental fatigue, Thakur and Mesh (2016) analyzed the impact that meditation can have on athletic performance. They argue that meditation reduces mental fatigue as over a six-week period it significantly improved performance among male basketball players compared to those in the control group.

These studies converge to highlight the importance mental fatigue can have on overall athletic performance. Additionally, Thakur and Mesh's study (2016) should make us hopeful that just as physical fatigue can be properly monitored to avoid this overtraining syndrome, mental fatigue can also be remedied. Just as universities and professional agencies have recognized the importance of physical recovery, they now need to recognize the similar importance of mental recovery.

To analyze the impact that mental fatigue has on team performance, this paper goes through a microanalysis of the Columbia Division I Varsity Field Hockey Team.

I. Field Hockey Overview

Field hockey is typically played on a 100-yard astro-turf field (see Figure 2). A 70-minute game with two halves, field hockey is 11 v. 11 without an offside rule. Players use a field hockey stick to touch and pass the ball. The ball cannot touch any part of the player's body, and, unlike ice hockey, players cannot use the reverse side of their stick.

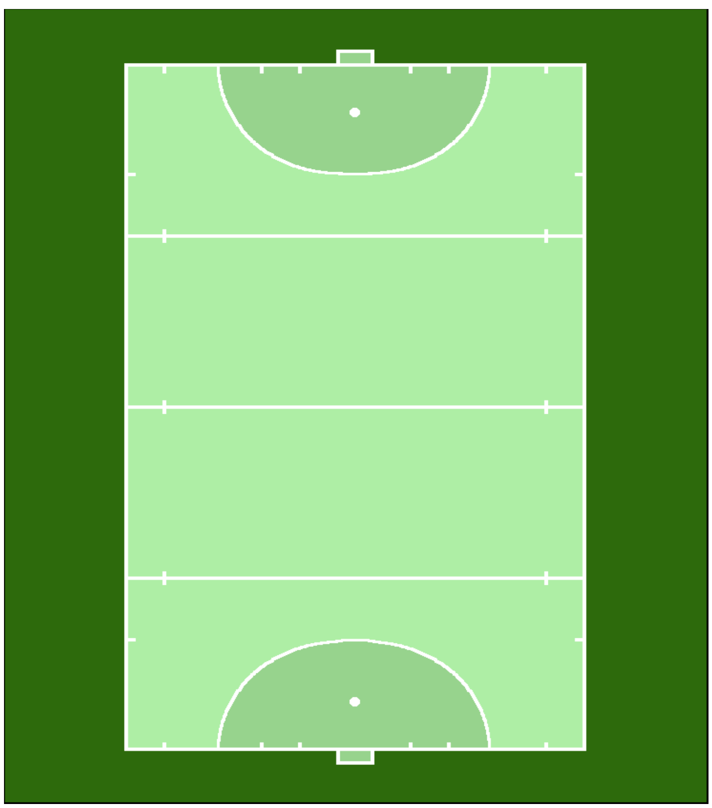

Figure 2: Field Layout

Each team can only score within their attacking circle—otherwise, the goal does not count. If the team on defense fouls in its own defensive circle (i.e. if the ball touches any part of their body, or if they illegally hit the other player's stick), then the offense receives a corner. On a corner, the attacking team can place as many players they want to on the circle edge, and the rest of their team remains on the 50-yard line. The defense gets four players inside the goal cage, while the rest of their team stays on the 50-yard line as well. The attacking team places the ball on the end line (the second hash mark from the goal on either side). Once the attack inserts the ball, which must go out of the circle, the defense can leave the cage and all players on the 50-yard line can run back.

From an attacking standpoint, a corner is a huge opportunity to score. Teams should ideally score on 33% of their corner opportunities. Yet, to score on a corner requires immense teamwork and mental attention. On a typical corner, four to five players will touch the ball before shooting on goal to throw off the defense. Thus, all players need to be highly aware and focused for successful execution.

The game ends after the second half; however, if there is a tie, then the game goes into two 15-minute overtime halves where the first team to score wins. The game will never end in a tie. If the game is still tied after the second half of overtime, then the game goes into shoot-outs.

II. Data Overview

To analyze the impact that mental fatigue has on winning, I examined the survey results from Columbia Varsity Field Hockey's past two seasons. Every day after practice, each player was required to fill out a survey that asked the players to self-assess on a wide range of metrics. The questions asked each athlete to rate: *sleep quantity, sleep* *quality, mental fatigue, soreness, physical fatigue, course load, stress, health, rate of perceived exertion (RPE),* and *overall being*. Athletes rated each metric on a 10-point scale. To assess *sleep quantity*, athletes rated the number of hours slept the night before practice from 1 to 10+. *Sleep quality, mental fatigue, soreness, physical fatigue, course load, stress, and RPE* were all evaluated so that 10 represented the ideal state of the athlete. In other words, a score of 10 meant that the athlete had a high quality of sleep the night before and had low mental fatigue, soreness, physical fatigue, course load, stress, and RPE. On the other hand, health and overall being were evaluated so that 10 represented ideal health and a positive overall being for that athlete.

The team filled out the survey daily for the Fall Season of both 2015 and 2016. The team played 17 games in each season; however, the surveys did not start until after the second game in 2015 and until after the fourth game in 2016. Thus, this analysis consists of an aggregate of 28 games.

To assess the impact mental fatigue had on the probability of winning, each game was coded for *Win* (1 for Win, 0 for Loss) and included multiple other variables. These metrics for both teams included the number of goals scored, shots, shots on goal, percent of shots on goal, number of corners drawn, corner success rate (i.e. of the corners drawn, what percent did the team score on), whether the game was held at home, whether the game was an Ivy Game, and the differential Ratings Percentage Index (RPI). RPI is the rating index that the NCAA uses to rank each team. The equation is as follows: RPI=.25*Win/Loss pct. +.50*Strength of Schedule(SOS)+.25*opponent'sSOS. Differential RPI (Differential RPI= Opponent's RPI – Columbia's RPI) was used to control for the different caliber of teams.

I had two main hypotheses prior to this analysis. First, I hypothesized that an increased mental fatigue throughout the week would decrease the team's probability of winning in that week. My second hypothesis was the mental fatigue from each day that week does not have an equal effect on the probability of wining.

To break down this first hypothesis, I wanted to know: if a game is hypothetically on Friday (games could be any day of the weekend, but I am just using Friday as an example), does the team's mental fatigue from Monday through Thursday impact the probability of winning. If I found that mental fatigue impacted the likelihood to win, then I would move on to my second hypothesis by assessing this impact on a day-to-day basis. For this hypothesis, I wanted to know: if the game was on Friday, does the team's mental fatigue on Thursday have a greater impact on the probability of winning than the team's mental fatigue on Wednesday?

III. Hypothesis #1

A. Empirical Strategy

To address my first hypothesis that the mental fatigue in the week leading up to a game affects the team's probability of winning, I created a modified mental fatigue variable: *pre-mental fatigue.* To create this new variable, I first took the data for the team's average mental fatigue on each day. *Pre-mental fatigue* averaged these team scores across multiple days. For example, for a game on Friday, *pre-mental fatigue* was the average of the team's mental fatigue from Monday through Thursday. *Pre-mental fatigue* for a game on Sunday averaged the team's mental fatigue from Monday through Saturday. *Pre-mental fatigue* reset at the start of every week so that it always was the average of Monday through the day prior to the game. Pre-variables for each metric from the survey were created to be included in the regressions. Below is a summary of all the new variables.

Table 1: Summary of Explanatory Variables

Variable:	Observations:	Mean:	Std. Dev.	Min:	Max:
Pre-Sleep Quantity	98	6.97	.52	5.65	8.41
Pre-Sleep Quality	98	6.77	.44	5.52	8.58
Pre-Health	98	6.54	.50	5.32	7.95
Pre-Overall Being	98	6.04	.52	4.38	7.05
Pre-Mental Fatigue	98	5.69	.55	4.18	6.75
Pre-Soreness	98	5.76	.58	4.27	6.81
Pre-Physical Fatigue	98	6.11	.55	4.09	7.07
Pre-Course Load	98	6.51	.86	4.08	7.90
Pre-Stress	98	6.23	.72	3.91	7.30
Pre-RPE	98	4.40	1.39	1.15	7.34

To determine which controls to include in a regression analysis, all of the survey metrics were correlated (see Table 2). Any variable with a correlation to *pre-mental fatigue* higher than .60 was eliminated. This elimination left four remaining variables: *pre-sleep quantity, pre-soreness, pre-physical fatigue*, and *pre-RPE*. Given the high correlation between *pre-soreness* and *pre-physical fatigue*, separate regressions were run so that these variables were isolated. Both regressions yielded statistically significant results at the 5%-level. As mentioned above, current research focuses on the impact physical fatigue has on athletic performance. Given this focus and given that this paper calls for greater consideration of mental fatigue in athletic analysis, I included the regressions with pre-physical fatigue as a control.

Table 2: Correlation Matrix of Explanatory Variables

Variable:	Pre-Sleep Quantity	Pre-Sleep Quality	Pre-Health	Pre-Overall Being	Pre-Mental Fatigue	Pre-Soreness	Pre-Physical Fatigue	Pre-Course Load	Pre-Stress	Pre-RPE
Pre-Sleep Quantity	1	-	-	-	-	-	-	-	-	-
Pre-Sleep Quality	.732	1	-	-	-	-	-	-	-	-
Pre-Health	.277	.432	1	-	-	-	-	-	-	-
Pre-Overall Being	.427	.511	.613	1	-	-	-	-	-	-
Pre-Mental Fatigue	-.455	-.639	-.692	-.756	1	-	-	-	-	-
Pre-Soreness	.074	-.033	-.102	-.322	.315	1	-	-	-	-
Pre-Physical Fatigue	-.047	-.246	-.313	-.537	.493	.918	1	-	-	-
Pre-Course Load	-.383	-.546	-.509	-.675	.877	.277	.398	1	-	-
Pre- Stress	-.446	-.644	-.554	-.717	.907	.264	.417	.964	1	-
Pre-RPE	-.692	-.586	.045	-.097	.146	.019	.071	.018	.105	1

B. Results

In this analysis, the dependent variable was winning. I regressed winning on mental fatigue and other control variables using both OLS and probit regression.

Prior to diving into a deep regression analysis, I first did a basic OLS regression. While this linear regression is not a perfect fit given the binary nature of the dependent variable, the coefficient is more interpretable. In this basic regression, we find that a one-point increase in a team's pre-mental fatigue decreases the probability of winning by .28 percentage points, which is significant at the 5% level (see Table 3).

Both probit models reveal a statistically significant impact of mental fatigue on the probability of winning at the 5% level. The results reinforce our hypothesis that an increase in mental fatigue throughout the week decreases the probability of winning the subsequent game. For both probit regressions, *Differential RPI* was also statistically significant at the 1% level, as the higher Columbia was ranked above the opposing team, the greater Columbia's probability of winning.

Table 3: Pre-Mental Fatigue and Winning

Regressor	**OLS (1)**	**Probit (2)**	**Probit (3)**
Pre-Mental Fatigue	-.284* p=.045 (.135)	-2.429* p=.041 (1.188)	-3.569* p=.025 (1.595)
Pre-Sleep Quantity	—	-1.427 p=.248 (1.235)	-1.429 p=.282 (1.400)
Pre-Physical Fatigue	—	1.246 p=.269 (1.127)	2.244 p=.109 (1.40)
Pre-RPE	—	1.685 p=.083 (.973)	2.663* p=.036 (1.268)
Differential RPI	—	.059** p=.004 (.021)	.091** p=.000 (.025)
Ivy Game	—	—	1.428 p=.068 (.783)
Intercept	2.154 p=.008 (.756)	7.554 p=.530 (12.01)	2.11 p=.873 (13.262)
R^2/PsuedoR^2	.086	.561	.601
n	28	28	28

Standard Errors are given in parenthesis. A (*) indicates statistical significance at the 5% level and (**) indicates statistical significance at the 1% level.

Additionally, under both probit models, the average marginal effects for pre-mental fatigue are significant at the 5% level (see Table 4). The only other variable with a significant average marginal effect is Differential RPI, but this effect is much smaller.

When controlling for whether the game was an Ivy Game, the impact of pre-mental fatigue became even more significant. When adding the Ivy-control variable, the average marginal effects of pre-mental fatigue increased by more than 10 percentage points. This increase implies that mental fatigue may have its biggest ramifications for games that matter most: conference games.

Table 4: Average Marginal Effects on the Probability of Winning

Regressor	Probit (2) Average Marginal Effects	Probit (3) Average Marginal Effects
Pre-Mental Fatigue	-.416** p=.009 (.158)	-.552** p=.003 (.186)
Pre-Sleep Quantity	-.244 p=.195 (.188)	-.221 p=.25 (.192)
Pre-Physical Fatigue	.213 p=.172 (.156)	.347* p=.029 (.159)
Pre-RPE	.288* p=.032 (.134)	.412** p=.007 (.152)
Differential RPI	.010** p=.000 (.0008)	.014** p=.000 (.002)
Ivy Game	—	.221 p=.113 (.139)

Standard Errors are given in parenthesis. A (*) indicates statistical significance at the 5% level and (**) indicates statistical significance at the 1% level.

In addition to analyzing the probability of winning, one should also assess how mental fatigue could impact other variables, particularly variables that require the most mental attention. Given the mental attention needed to execute corners, I regressed the *number of corners drawn* and *corner success rate* on *pre-mental fatigue* (see Table 5). *Pre-mental fatigue* did not significantly impact the number of corners Columbia drew in a game; however, at the nearly 5% level, *pre-mental fatigue* did impact the success rate of the corners drawn. In fact, a 1-point increase in *pre-mental fatigue* decreased the success rate of corners by 11.47 percentage points. Most coaches would argue that in close games, corners are often the deciding factor; thus, mental fatigue's impact on corner success rate has large implications for a team's overall success.

Table 5: Mental Fatigue's Effect on Corners and Corner Success Rate

Regressor	**OLS (4) DV=# of Corners Drawn**	**OLS (5) DV= Success of Corners**
Pre-Mental Fatigue	-1.028 p=.454 (1.348)	-.114 p=.063 (.058)
Pre-Sleep Quantity	-2.282 p=.351 (2.394)	-.111 p=.194 (.083)
Pre-Physical Fatigue	.532 p=.773 (1.825)	.114 p=.107 (.068)
Pre-RPE	1.631 p=.229 (1.319)	-.033 p=.458 (.043)
Differential RPI	.052* p=.039 (.024)	-.001 p=.446 (.001)
Intercept	17.48 p=.490 ()24.924	.985 p=.187 (.723)
R^2	.233	.140
n	28	28

Standard Errors are given in parenthesis. A (*) indicates statistical significance at the 5% level and (**) indicates statistical significance at the 1% level.

IV. Hypothesis #2

A. Empirical Strategy

Given that the above results confirmed the first hypothesis, further evaluation of mental fatigue's impact on winning was necessary. To address the second hypothesis that the impact of mental fatigue will vary as a function of number of days prior to the game, I created six new mental fatigue variables. I created *mental fatigue_1, mental fatigue_2, up to mental_fatigue_6*. *Mental fatigue_1* is the team's average mental fatigue score the day prior to a game and *mental fatigue_6* is the team's average mental fatigue score six days prior to a game. If a game were on Friday, then *mental fatigue_1* would be the team's average mental fatigue from Thursday. I created *variable_1* to *variable_6* for each survey metric and then ran the same regressions from the first hypothesis.

A. Results

Only *mental fatigue_1* and *mental fatigue_4* had a statistically significant impact on winning at the 1% level. Both an increase in *mental fatigue_1* and *mental fatigue_4* decreased the team's probability of winning. *Mental fatigue_2, mental fatigue_3, mental fatigue_5,* and *mental fatigue_6* did not significantly impact the probability of winning. This result places emphasis on mental recovery the day before a game, as higher mental fatigue two and three days before a game do not seem as impactful. Most important to note, one day leading up to a game, every variable had a statistically significant impact at the 5% level. *Physical fatigue_1*and *physical fatigue_4* actually had a positive impact on winning. This result does not contradict prior research about physical fatigue, but rather most likely exists because of the team's proper physical recovery. Physical fatigue is not synonymous with the overtraining syndrome. As we saw in Budgett's model (1998), difficult training combined with proper recovery, increases athletic performance. Thus, this positive impact of physical fatigue on winning reinforces this hypothesis.

Table 6: Mental Fatigue's Day-by-Day Effect on Winning

Regressor	Probit for variable_(1) Impact of scores 1 day prior to game day (6)	Marginal Effects from 1 day prior to game day	Probit for variable_(4) Impact of scores 4 days prior to game day (7)	Marginal Effects from 4 days prior to game day
MentalFatigue_ (X days prior)	-2.83** p=.000 (.739)	-.444** p=.002 (.140)	-2.71** p=.005 (.955)	-.193* p=.024 (.085)
SleepQuantity_ (X days prior)	-2.193** p=.001 (.542)	-.343** p=.000 (.095)	-2.513* p=.034 (1.186)	.179** p=.000 (.050)
PhysicalFatigue _(X days prior)	2.464** p=.001 (.727)	.385** p=.001 (.117)	2.243* p=.018 (.949)	.160* p=.029 (.073)
RPE_(X days prior)	-.813* p=.012 (.324)	-.127* p=.048 (.064)	-.123 p=.607 (.240)	-.008 p=.602 (.016)
DifferentialRPI	.056** p=.006 (.020)	.008** p=.000 (.001)	.203** p=.000 (.058)	.014** p=.000 (.002)
Intercept	21.002** p=.000 (5.267)	_	-12.570 p=.221 (11.096)	_
R^2/PsuedoR^2	.582	_	.807	_
n	27	27	26	26

Standard Errors are given in parenthesis. A (*) indicates significance at the 5% level and (**) indicates significance at the 1% level.

Even though the average marginal effects for *mental fatigue_4* were significantly smaller than those of m*ental fatigue_1*, the significant result at day four is nonetheless thought provoking. Columbia's rest day was every Monday—four days prior to Friday games. The result could highlight the importance of a proper rest day not just physically but also mentally. More research should be conducted to analyze the importance of proper mental recovery on off-days.

Given the prior significant results we found with regard to corners, a day-by-day analysis was executed (see Table 7).

Table 7: Mental Fatigue's Day-by-Day Effect on Number of Corners Drawn and Corner Success Rate

Regressor	OLS (1) DV=# of Corners based on results 1 day prior to game	OLS (2) DV= Success of Corners based on results 1 day prior to game	OLS (2) DV= Success of Corners based on results 2 days prior to game
MentalFatigue_(X days prior)	-.222 p=.905 (1.836)	-.127** p=.010 (.044)	-.096* p=.017 (.037)
SleepQuantity_(X days prior)	-.395 p=.713 (1.058)	.005 p=.850 (.028)	-.068 p=.076 (.036)
PhysicalFatigue_(X days prior)	1.175 p=.598 (2.198)	.134* p=.044 (.062)	.143* p=.032 (.062)
RPE_(X days prior)	-.278 p=.690 (.690)	-.101** p=.001 (.027)	-.045 p=.167 (.031)
DifferentialRPI	.050 p=.120 (.030)	-.003* p=.033 (.001)	-.001 p=.097 (.001)
Intercept	5.994 p=.620 (11.918)	.497 p=.160 (.341)	.514 p=.098 (.295)
R^2	.141	.110	.368
n	27	27	26

Standard Errors are given in parenthesis. A (*) indicates statistical significance at the 5% level and (**) indicates statistical significance at the 1% level.

As found in our first analysis, mental fatigue did not impact the number of corners drawn, but it did impact the corner success rate such that increased mental fatigue decreased corner success rate. We found only significant results for one and two days prior to a game, although the impact on two days prior was approximately two percentage points lower. A one-point increase in the mental fatigue one day prior to a game decreased corner success rate by approximately 12.7 percentage points, while a one-point increase in mental fatigue two days prior to a game decreased corner success rate by approximately 9.6 percentage points. Again, given the refined mental attention needed to successfully execute corners, this result implies the negative impact poor mental recovery could have on a team's overall success. Additionally, these results stress the importance of mental recovery, especially on the days closest to games.

To note, although *mental fatigue_4* impacted the probability of winning, *mental fatigue_4* did not significantly impact corner success rate. While this result may create possible doubt for the prior theory about recovery days, further research should still be done to isolate the impact of successful mental fatigue recovery on rest-days.

V. Conclusion

Our results confirm both hypotheses. First, mental fatigue and winning have a negative relationship. Second, this relationship is particularly strong for the day and second day prior to a game. Additionally, athletic skills requiring increased mental focus may be most likely to suffer from this main effect of mental fatigue one and two days prior to a game.

These results imply greater implications for athletic training and recovery. Most research has focused on the importance of proper physical recovery. Coaches and trainers stress protein shakes, adequate sleep, foam rolling, stretching, and off-days to reduce an athlete's physical fatigue. Of course, these elements should be stressed, since physical fatigue can cause a decline in athletic performance. However, research has shown that proper physical recovery prevents the decline in athletic performance due to physical fatigue (Budgett, 1998). Budgett's research (1998) highlights how over time, with hard workouts and good recovery, athletic performance will increase. The positive significant effects found in regards to physical fatigue one and two days prior to a game on corner success rate reinforces Budgett's initial findings. Thus, even though mental fatigue and mental recovery are treated as inferior to physical fatigue and physical recovery, could mental fatigue work under a similar framework? Perhaps coaches should find ways to "exercise" their players' mental fatigue along with their physical fatigue. If mental fatigue and physical fatigue operate under the same mechanisms, then proper recovery should lead to a boost in athletic performance not just from physical recovery but also mental recovery. Thus, we must take the same care to monitor mental fatigue as we do with physical fatigue, so that we can help athletes reach their maximum athletic performance.

Further research must be conducted so that we can expand our understanding of mental fatigue's impact on team's performance. What are the best practices to helping athletes recover mentally? Additionally, should teams focus more attention on increasing their players' "mental game?" Would a stronger mental game decrease susceptibility to mental fatigue's adverse effects on athletic performance?

While not enough research has been done to answer all of these questions, the modest research that has been done in this domain reminds us of the negative impacts mental fatigue can have on a team's success. Yet, research, like Thakur and Mesh's study, gives us hope that with proper monitoring, a team's mental fatigue is just as avoidable as physical fatigue.

This paper's findings remind us that the conversation needs to evolve so that recovery is no longer thought of as a solely physical process. Instead, the conversation must stress recovery as both a physical and mental process. Teams who are first to the market in this understanding will have the opportunity to drive even greater improvements in athletic performance than teams who focus solely on physical recovery.

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