

WHOOP

SLEEP AS A PREDICTOR OF SWIMMING PERFORMANCE IN NCAA, DIVISION I COLLEGIATE ATHLETES

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Introduction

This report presents evidence that (1) longer time spent asleep and longer time spent in REM sleep are both positively correlated with next-day swimming performance and (2) athletes on the WHOOP system were able to use the provided analytics to positively impact their sleep patterns from mid-season to the championships. This report also introduces the elite college swimmer as an ideal subject for investigating the effects of sleep duration and quality on athletic performance. Finally, a novel method of measuring performance improvements is introduced which is robust against performance variations caused by cycles of training and tapering.

Background

One can analyze the performance of a swimmer by critiquing technique, but what ultimately matters is the time to complete a given race. Race distances are set to a limited number of fixed lengths. There are only four different strokes competed, (1) freestyle, (2) backstroke, (3) breaststroke and (4) butterfly; competitions include dedicated races for each stroke in addition to Medley events that include all four.

Competition pools are standard lengths, starting boards are standard heights and fresh water naturally is the same density and viscosity at all competition locations. These standardizations remove many of the confounding factors found in other individual sports like running, cycling, and rowing. The competition results for elite swimmers vary extremely little from meet to meet. When races are won and lost by sometimes hundredths of a second, even tiny performance improvements can be significant to an athlete.

Evaluating Performance Changes

The NCAA Championship winners are determined by races held in a single championship weekend at the end of the season. Coaches therefore prescribe athletes significantly reduced training volumes approaching this extremely important event in order to ensure that athletes are well rested and positioned to achieve their best times. Numerous studies have shown this strategy, known as “tapering,” results in improved performance¹. The practice of tapering creates large within-season performance variations, which make it difficult to compare performance achieved in different meets at different points of the season. To control for this, the authors examined seasonal trends from 1.2 million Division I swimming races taking place over the past eight years.

In order to make meaningful comparisons among athletes, each race time was normalized to the athlete’s personal best time for a given race. To compare seasons across years, all event dates were stored by the integer number of days before the NCAA championship competition for that year (separately for men and women).

The results from this historical data show very strong trends in performance, with reduced performance during the training season followed by increased performance towards the end of the season. The trends presented in Figure 1 demonstrate the effectiveness of tapering

¹ Hooper et al., 1998



with individuals on-average achieving their best in-season performance at the championship events. The effects were consistent across all strokes and distances.

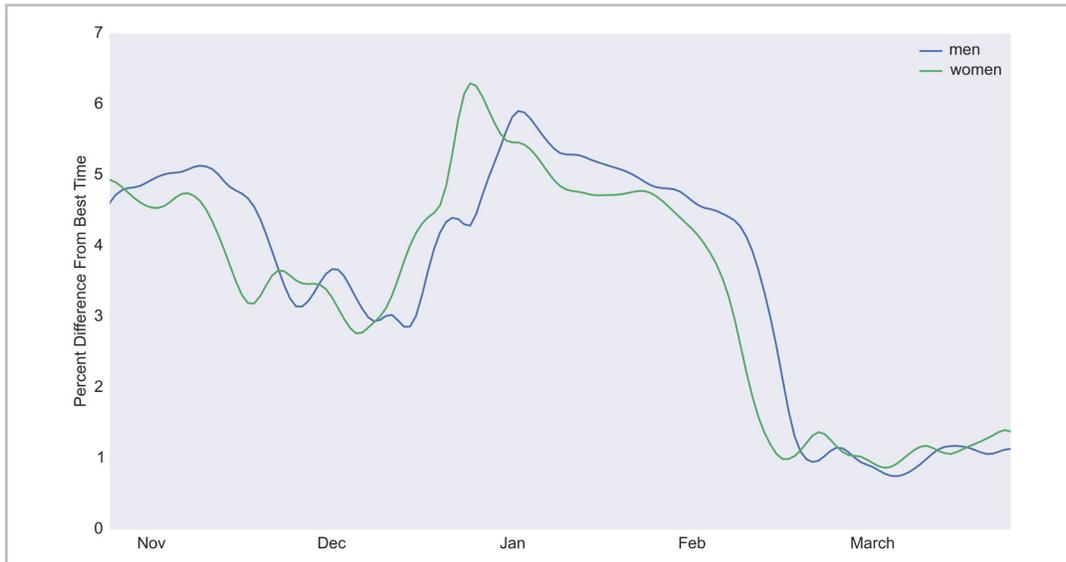


Figure 1. The natural variation in swimming race times as affected by seasonal training patterns. The x-axis shows the time within the season. The y-axis shows the percent difference between an athlete’s best time in a particular event and their median times. During the most intense training periods in Jan and February, the race times increase, while at the end of the season median times are within 1% of the best times. Achieving a personal best is a rare event, so the median times will always be above the personal best.

The within-season variation in performance shown in **Figure 1** is larger than the performance variation between years. To measure diminutive performance deviations that may be caused by non-seasonal factors, such as sleep, we compared each athlete’s race times this season with races that occurred in previous years and in a similar period within the season. For example, an athlete’s times competing 21 days before the championship this year, would be compared to a couple races they swam last year, 20 and 21 days away from that year’s championship.

There was not enough data for any single race to plot distributions, but we were able to compare data from multiple races on the same chart by measuring a percent difference in race times, rather than an absolute difference in seconds. This comparison works because the variance in race time distributions is roughly proportional to median race time for all strokes and distances we analyzed.

Data Collection

During the 2016 swimming season, 43 collegiate athletes in two top-ranked NCAA Division I swimming teams trained using the WHOOP performance optimization system. The WHOOP platform consists of a waterproof continuous-wear vital sign monitoring device, which captures heart rate, heart rate variability, galvanic skin response, 3D acceleration, and ambient temperature 100 times a second, 24 hours a day. This hardware communicates with



WHOOP's mobile applications via Bluetooth, where it is then relayed to a cloud-based analytics platform. The continuous-wear nature of the WHOOP device allows for advanced monitoring of both sleep and training on the same platform. The athletes specified in the app the times they dedicated to sleep, and the analytics algorithms calculated the amount of that time for which they were asleep, and the amount of time in which they were in REM sleep.

Most of the athletes analyzed here have specialized in three different events, with times in those events very rarely deviating more than a few percentage points from the athlete's median times. This level of elite performance is well above the typical NCAA Division I athlete. Because these athletes are swimming at such a high level, their performance is incredibly consistent, making even minor deviations in individual performance significant.

Analysis

We see a persistent positive correlation between the duration of an athlete's sleep and the resulting performance improvement. The data show that more time spent asleep during the two days before the meet, the greater the likelihood of an athlete improving their performance over previous years. These results for swimmers are very much in line with previous research that showed that athletic performance is affected by sleep^{2,3}.

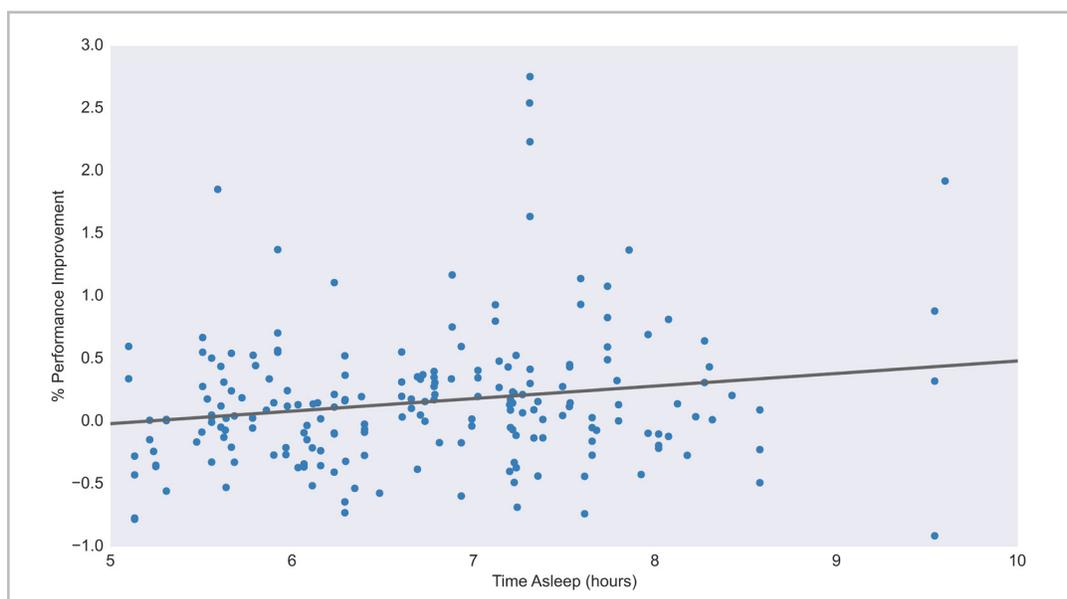


Figure 2. Increasing time asleep is shown to be correlated with increased athletic performance. Each datapoint on the chart represents a different race by an athlete, coupled with information about their sleep before the race. The y-axis shows the percent difference in speed an athlete achieved in the races this year, for which we have sleep data, and races swam around the same time of the season in previous years. The x-axis shows the amount of time the athlete dedicated to sleep self reported through the WHOOP mobile application. The solid line is a least squares linear fit through the points.

² Mah et al., 2011

³ Reilly et al., 2007



Sleep is not a singular physiological state, but rather is composed of a set of distinct physiological states with unique processes and purposes. As part of WHOOP’s comprehensive sleep analysis, WHOOP calculates the time spent in each stage of sleep. REM sleep has been shown to be important for reducing fatigue and improving learning and cognitive performance^{4,5}. When we graph the same performance differences shown in **Figure 2**, but compared to REM sleep attained on the night prior to competition, we see that even small changes in REM sleep duration correlate with improvements in performance. This indicates that REM sleep is a more powerful indicator of performance than simply hours in bed. It is therefore clear that an analytical approach, which includes measures of sleep quality in addition to sleep quantity is advantageous to understanding an athlete’s readiness to compete.

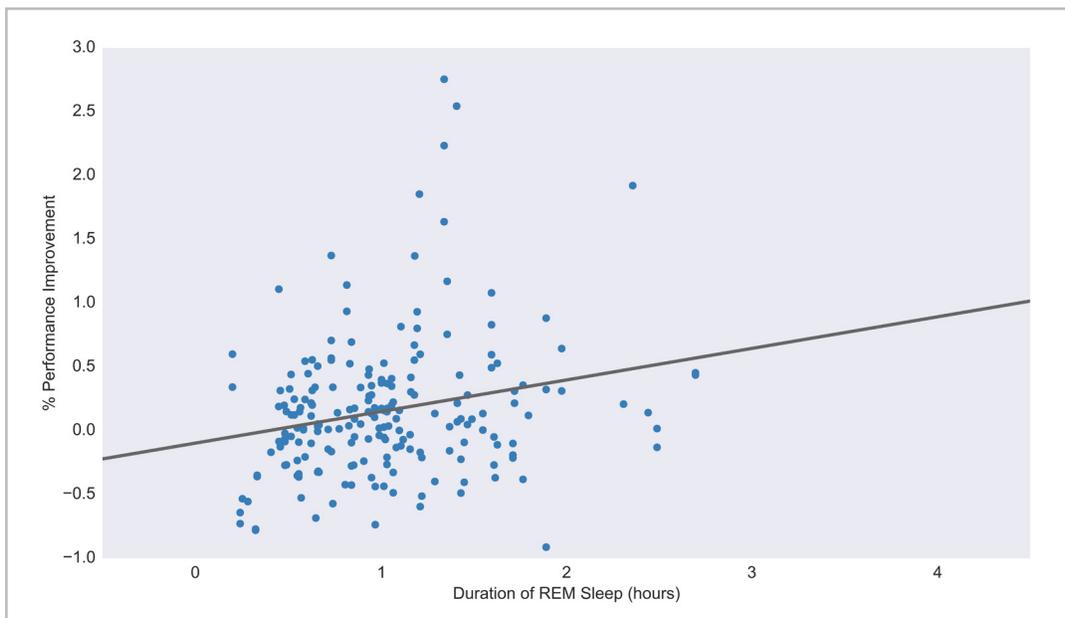


Figure 3. Increasing amounts of Rapid Eye Movement Sleep (REM Sleep) is shown to be correlated with sharply increased athletic performance. Each data point on the chart represents a different race by an athlete, coupled with information about their sleep before the race. The y axis shows the percent difference in speed an athlete achieved in the races this year, for which we have sleep data, and races swam around the same time of the season in previous years. The x axis shows the amount of time the athlete spent in REM sleep, as calculated by WHOOP’s proprietary sleep staging algorithm. The solid line is a least squares linear fit through the points.

One of the key elements to inducing behaviour change is ready feedback. The WHOOP system is designed to give athletes near-real time feedback on their night’s sleep, including time spent in each sleep stage. This allows the athletes to learn the factors that affect the duration and quality of their sleep in time to make the lifestyle modifications they need to make positive changes. The data from our users show that over the course of the season, athletes made improvements in their sleep. The histogram in **Figure 4** shows the time in bed

⁴ Shephard, 1984

⁵ Lubin, A., et al. (1974)



in the week leading up to a swim meet during the season, compared with the time in bed in the week prior to each athlete's championship meet. The time in bed is not only greater, but also more consistent in duration, both of which have been shown to be important for cognitive performance⁶.

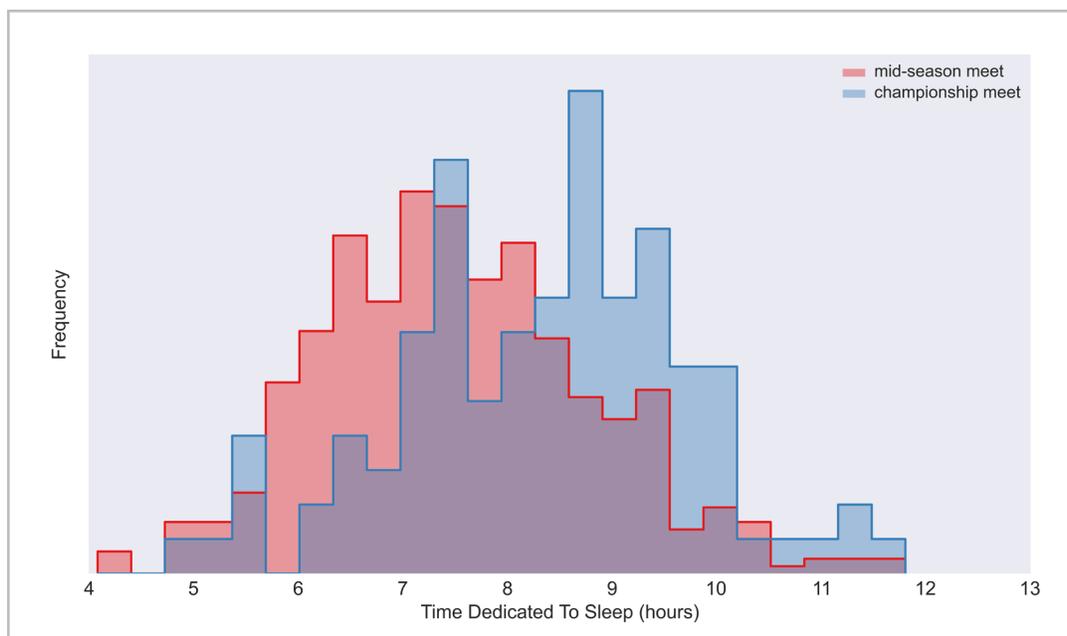


Figure 4. Athletes using the WHOOP system are shown to sleep more in the week prior to a championship meet than in a week prior to a mid-season meet. The x axis of this histogram represents the amount of time the athletes dedicated to sleep as self reported through the WHOOP mobile application. Of the 7 nights prior to the championship meet and the 7 night prior to each of the mid-season meets, the y axis is proportional to the amount of times that fell into each hour bin.

But time dedicated to sleep is only as good as the time actually spent asleep, which was demonstrated earlier to be a predictor of performance in a swimming meet. When graphing the average duration of time spent asleep in nights the week before a championship meet, we see that athletes are getting much more time asleep before their championships.

The results demonstrated with the limited sample here have also been observed for all collegiate athletes on the WHOOP system. In a separate report released earlier this year⁷, we showed that the longer athletes are on the WHOOP system, the more time they dedicate to sleep each night and unreleased data show that they also spend more time actually asleep the longer they are the WHOOP system. By giving feedback about sleep quality every morning, the WHOOP system empowers athletes with the knowledge of what affects their sleep quality. The results in **Figure 4** show that athletes are using that knowledge to improve sleep when they need it the most.

⁶ Barber et al., 2010

⁷ Breslow, 2016

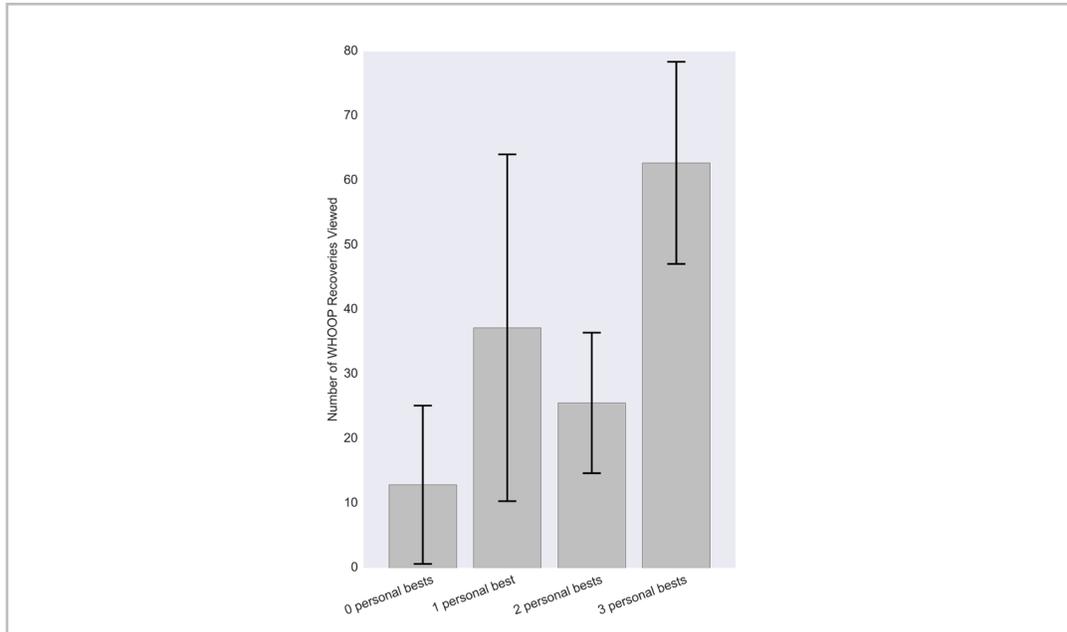


Figure 6. Athletes more actively tracking their sleep using the WHOOP system are shown to achieve more personal best times during championships. The x axis bins athletes into the number of personal best times they achieved, from 0 to 3. The height of the bar is the average number of sleeps logged with the WHOOP system and the error bars show the standard deviation. The athletes were shown the WHOOP analysis of sleep quality for every sleep that was logged.

By comparing the athlete’s swimming times in the season that they used WHOOP, to their times in seasons that they did not use WHOOP, we measure if an athlete beat their personal best time. The data show that the athletes who received the most feedback from WHOOP about their sleep, achieved the most success in their championship races. As in the with the data in the rest of this report, we only considered personal bests in the races that each athlete was specializing in.



Conclusion

The analysis in this report shows that increased time spent asleep is correlated with increased athletic performance. These results are consistent with both extant academic literature on the topic and previously released internal investigations by the WHOOP data science team. This particular method of evaluating performance improvements compared with previous years is advantageous because it is individually tailored to each athlete, thereby allowing for meaningful results despite the small magnitude of the changes. One drawback of the approach taken here is that the athletes analyzed in this report did not train with WHOOP in previous years. Accordingly, we know nothing of their time dedicated to sleep in the races that form a basis for comparison. Next season, with the availability of two years of data we will be able to do pairwise comparisons and will likely result in even stronger correlations.

In conclusion, we've demonstrated that both time spent asleep and time spent in REM sleep are positively correlated with performance, and that with the help of the WHOOP system, athletes are able to positively impact their sleep patterns and achieve more time spent asleep in preparation for a championship meet. At the end of the season, the athletes who were more engaged with the WHOOP platform achieved better race times in the championships than their teammates who were less engaged.



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