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The Impact of Sleep on Mental Toughness: Evidence From Observational and N-of-1 Manipulation Studies in Athletes

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The purpose of this study was to explore the direction and magnitude of the relationship between sleep and mental toughness and examine the effect of time in bed extension and restriction on mental toughness. Study 1 was an observational study examining the relationship between sleep quality and duration (hours) and mental toughness in 181 participants. Winsorized correlations revealed both longer sleep duration (ρ_ω = .176 [.033, .316], p = .016) and higher quality (ρ_ω = .412 [.270, .541], $p \leq .001$) were associated with increased mental toughness. Follow-up regression analyses revealed sleep quality (b = 0.177, [0.117, 0,238], $p \leq .001$), but not sleep duration (b = 0.450, [−0.3254, 1.22], p = .256), predicted mental toughness score. In Study 2, we utilized a longitudinal N-of-1 influenced methodology with 6 participants to further examine whether manipulated time in bed (i.e., sleep duration) influenced mental toughness. Participants recorded sleep quality, duration, and mental toughness over 5 weekdays during 2 separate 2-week periods of baseline (normal sleeping pattern) followed by manipulated time in bed (counterbalanced 9 hr or 5 hr). Visual analyses (including determination of nonoverlapping data points between baseline and intervention weeks) revealed reduced time in bed negatively impacted the mental toughness of 4 of the participants. Social validation interviews were conducted to further explore participants' perceptions of the sleep manipulation. A cumulative effect of reduced sleep on mental toughness was noted by specific individuals. In addition, participants identified potential buoys of mental toughness in the absence of sleep.

Keywords: sleep, mental toughness, masters athletes, N-of-1, sleep duration

Supplemental materials: http://dx.doi.org/10.1037/spy0000174.supp

Mental toughness is a personal capacity to achieve consistently high levels of performance despite challenges and stressors (Gucciardi, Hanton, Gordon, Mallett, & Temby, 2015). Despite some existing conceptual disagreement about its exact nature (e.g., whether it is multidimensional or unidimensional), it is broadly agreed that mental toughness is amenable to change and at least partially state-like (Gucciardi et al., 2015). As such, research is warranted that explores the potential antecedents of changes in mental toughness across different states. Two potential antecedents that warrant further exploration are the quality and duration of sleep, as they are both positively associated with several proposed components of mental toughness (e.g., attentional control and emotional regulation; Baum et al., 2014; Krizan & Herlache, 2016; Tempesta, Socci, De Gennaro, & Ferrara, 2018), as well as physical and cognitive performance (e.g., psychomotor vigilance: Belenky et al., 2003).

Researchers have suggested that mental toughness represents a higher order construct comprising a range of lower order variables. For example, Gucciardi et al. (2015) referenced a mental toughness "resource caravan" (Hobfoll, 2011) or aggregation of several personal re-

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sources that interweave to drive performance. These individual resources (e.g., emotional regulation, self-efficacy, optimism, and attention regulation; Stajkovic, 2006) are tied together so people high in one are usually high in others. Although previous studies have revealed that sleep disruption negatively influences several mental toughness resources (e.g., emotional regulation: Goldstein & Walker, 2014; and attentional regulation: Killgore, 2010), we believe that sleep disruption will negatively influence the broader construct of mental toughness as a whole, and sleep extension (or increasing sleep quality) may positively influence mental toughness.

Indeed, recent evidence demonstrates mental toughness and sleep are related (Brand et al., 2014; Sadeghi Bahmani et al., 2016). Brand et al. (2014) found mental toughness to be associated with sleep quantity in adolescents. The authors suggested that individuals higher in mental toughness achieve better sleep than their less mentally tough counterparts because mental toughness buffers stress, which can influence sleep onset latency and sleep quality (Lemola, Ledermann, & Friedman, 2013). Sadeghi Bahmani et al. (2016) also examined mental toughness and sleep across multiple populations, and Lemola et al. (2013) looked at sleep variability and subjective well-being. However, the question about whether a change in sleep quality or duration—constructs that individuals, coaches, and others could potentially choose to adjust in their lives—influences mental toughness has not been addressed in the literature. Sleep can be reasonably hypothesized as an antecedent (and likely consequent) of self-reported mental toughness based on the previously demonstrated research on mental toughness subdimensions. To this end, the purpose of this two-part study was to explore the direction and magnitude of the relationship between sleep (duration and quality) and mental toughness and examine the effect of time in bed extension and restriction on mental toughness and sleep quality.

Experiment 1

Method

Participants. Following ethical approval from K. Bradford Cooper's institutional research ethics committee, 218 adult participants partaking in some version of self-selected and defined exercise at least three times per week were recruited through convenience online sampling. Participants were recruited via social media and e-mail, and additional personal details such as age or specific location were not part of the survey data. We invited the participants to complete two surveys that explored their duration and quality of their sleep and mental toughness. Determination of sample size was based on a Pearson correlation coefficient of .39 between sleep quality and mental toughness found by Brand et al. (2014). By stipulating a power of .80, significance level of .05 and effect size .10 using G*Power (Version 3.1.9.2, Universitat Kiel, Germany), our sample size was estimated to be 100 (Faul, Erdfelder, Lang, & Buchner, 2007). Of the original 218 individuals who registered to participate, 181 completed both sleep and mental toughness measures. The remaining participants only completed one of the two assessments and were therefore excluded from subsequent analysis. Data from Experiment 1 has not been previously published.

Measures.

Sleep. Sleep duration was based on self-reported time in bed. We simplified tracking of this for participants by requesting time in bed to the nearest 0.5 hr rather than asking participants to identify an exact number of hours and minutes sleep due to the variation noted in self-reported sleep quantity (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). Sleep quality was assessed using the Richards-Campbell Sleep Questionnaire (RCSQ) because it provides an effective assessment of the previous night's sleep (Hoey, Fulbrook, & Douglas, 2014). The RCSQ was originally developed to assess the quality of sleep in hospital patients from the previous night. It involves five questions with a score of zero (e.g., "bad night's sleep") to 100 (e.g., "good night's sleep") for each. An average score of zero to 100 provides an overall comparison of sleep quality.

Mental toughness. The unidimensional Mental Toughness Index (MTI; Gucciardi et al., 2015) an eight-question, 7-point Likert scale self-assessment, was utilized to assess mental toughness. It prompts participants to indicate the accuracy of a specific statement, ranging from one (*100% False*) to seven (*100% True*). Total scores range from 8 to 56, with higher scores indicating higher mental toughness, and

MTI has been shown (Gucciardi et al., 2015) to be reliable (p = .860–0.890), provide strong factor loadings, and high (0.900) Cronbach's α (Jones & Parker, 2018).

Procedure. Participants were randomly assigned to complete their two assessments (sleep duration/quality in the morning for immediate recall and MTI at approximately 16:00 hr as a review of their mental toughness for that specific day) on one of five week days (Monday–Friday) and received an e-mail reminder on their assigned day. The assessment was completed via a computerized assessment process, so of the 181 individuals who completed both assessments, there was no missing data because the online system prompted users to address missing data before submission. Our goal with Experiment 1 was to attempt to replicate Brand et al.'s (2014) positive association between mental toughness and sleep with adolescents, with a range of adult participants, thus setting the stage for exploring causality in Experiment 2.

Results

Data screening and analysis. Data analysis was performed utilizing R (available in the online supplemental materials). We examined the data for the assumptions of ordinary least squares regression (normality of residuals, and outliers) and found univariate outliers for both sleep quality and sleep duration. A decision was made to retain the outliers because evidence for data error was lacking, and the outliers appeared to be legitimate members of the population. However, the data violated the assumption of normality, and therefore we adopted Winsorized correlations with 95% confidence intervals and robust regression (Wilcox, 2017) using a maximum likelihood estimator. Winsorized means (compared with the more common Pearson correlations) provide a more robust measure of the sample mean by replacing the most extreme high and low values with the next highest (smallest) values (Wilcox, 2017). Next, we calculated descriptive statistics and calculated internal reliability estimates from the MTI and RCSQ scores (Table 1). Finally, our Winzorized correlational analyses demonstrated that both longer sleep duration (ρ_ω = .176 [.033, .316], p = .016) and higher quality sleep (ρ_ω = .412 [.270, .541], $p \leq .001$) were associated with MTI score. Follow-up robust regression analyses revealed that sleep quality predicted MTI score (b = 0.177, [0.117, 0,238], $p \leq .001$); however sleep duration did not (b = 0.450, [−0.3254, 1.22], p = .256) at the $p \leq .05$ level (Table 2).

Discussion

This initial experiment confirmed our hypothesis that a positive association exists between mental toughness and both sleep quality and duration, suggesting that the relationship previously found for adolescents (Brand et al., 2014) holds for adults. However, the regression analysis showed that duration did not directly predict the MTI score. Tabachnick and Fidell (2013) suggested that a significant correlation and a nonsignificant regression coefficient could indicate the omission of a potentially important mediating variable. Future researchers may wish to examine potential mediator or suppressor variables. For example, cognitive strategies, such as positive reappraisal, could buffer the deleterious effect of sleep restriction and thus maintain perceived mental toughness (Gaudreau, Blondin, & Lapierre, 2002), potentially explaining the nonsignificant regression coefficient found in this experiment.

Table 1
Descriptive Statistics and Internal Reliability Estimates for Mental Toughness, Sleep Duration, and Sleep Quality

Descriptor	*M*	*Mdn*	*SD*	Winsorized *M*	Winsorized *SE*	Cronbach's α	Composite reliability
Mental toughness	44.193	46	6.580	44.812	0.436	.780	.869
S.Duration	7.160	7	1.176	7.257	0.073	—	—
S.Quality	63.138	67.5	15.007	65.077	1.223	.770	.811

Note. S.Duration = sleep duration; S.Quality = sleep quality.

Table 2
Winsorized Correlations Between Mental Toughness, Sleep Duration, and Sleep Quality and Robust Multiple Regression Analysis Predicting MTI Score From Sleep Duration and Sleep Quality

	Winsorized correlations ρ_ω [LLCI, ULCI]		Robust regression				
Variables	MTI	S.Duration	*b*	95% CI for *b*	*SE*	*t* value	*p*
Constant	—	—	30.088	[25.006, 35.169]	2.593	11.604	≤.001
S.Duration	.176 [.033, .316], *p* = .016		.450	[−0.3254, 1.22]	.395	1.139	.256
S.Quality	.412 [.270, .541], *p* ≤ .001	.403 [.269, .524], *p* ≤ .001	.177	[0.117, 0.238]	.030	5.738	≤.001

Note. Winsorized correlation = ρ_ω with 95% confidence intervals based on 10,000 bootstrapped sample and 20% Winsorizing; *b* = unstandardized regression coefficient; CI = confidence interval; LLCI = lower level CI; ULCI = upper level CI; *SE* = standard error for the unstandardized regression coefficient; *p* = probability value.

Our second experiment aimed to extend these findings by experimentally extending or restricting time in bed to see whether this influenced perceived mental toughness. We also aimed to examine the participants' experiences of the time in bed manipulation to explore whether the participants used any specific psychological strategies in response to sleep extension and restriction.

Experiment 2

The purpose of this experiment was to examine the effect of time in bed extension and restriction on mental toughness. N-of-1 studies examine the effects of treatment by following an individual participant over time as the treatment (in this case, total time in bed) is varied from period to period, and provide an effective way of examining real-world interventions for a single individual (Araujo, Julious, & Senn, 2016). Conducting an idiographic analysis of the effect of time in bed extension and restriction on sleep quality and mental toughness is needed because Experiment 1 revealed a relationship. However, individual differences in sleep need and sleep behavior (Spilsbury et al., 2004) mean that a group-based design cannot effectively reveal the individual effects (McDonald et al., 2017). We hypothesized that lower MTI self-assessment scores would occur during the reduced time in bed period and that higher MTI scores might occur during the period of increased time in bed. Follow-up interviews allowed us to explore the possible cause of any changes.

Method

Design. We adopted principles and practices associated with an N-of-1 study model (McDonald et al., 2017; Vieira, McDonald, Araújo-Soares, Sniehotta, & Henderson, 2017). An N-of-1 methodology is a valid and efficient approach for both the development and evaluation of interventions (Lillie et al., 2011), and the testing of theory (Johnston & Johnston, 2013). Our N-of-1 study is individualized and not intended to infer population-level parameters. It consists of time-series data to measure variability within individual participants over that time, and therefore, the design emphasizes real-world considerations related to the individual.

Participants. Study participants were initially recruited from among the 13 elite masters athletes who participated in a previous study (Cooper, Wilson, & Jones, 2019). Six athletes volunteered (see Table 3 for demographic information) to participate, and all six completed the entire study. A recent review of 34 different N-of-1 study designs (McDonald et al., 2017) reported a mean sample size of five participants and a median of four. With potential for dropout from the study due to the sleep manipulation over the 4 weeks, we recruited all six participants who volunteered.

Measures. Sleep duration (to nearest 0.5 hr), MTI (MTI), and RCSQ were utilized in the same format as Experiment 1. This was done for consistency across the two experiments.

Procedure. Participants completed 5 days of baseline assessments on Monday through Friday during the selected weeks. These assessments included recording their sleep duration from the previous night to the nearest 0.5 hr and sleep quality using the RCSQ in a morning self-assessment. They then completed a mental toughness assessment using MTI at approximately 16:00 hr each day. The sleep schedule during this initial 5-day period was self-selected by participants. During Week 2, the first of two sleep opportunity–manipulation weeks, the six participants were randomly assigned to either a 5-hr or a 9-hr time in bed-manipulation schedule (three people assigned to each group). Participants completed the same morning and afternoon self-assessments as baseline week (also Monday through Friday). Following a 4-week reset period during which no assessments or sleep manipulation was included, the process was repeated. Participants first completed a second baseline (regular for that individual) sleep schedule week, before completing the alternative sleep manipulation schedule (5 or 9 hr).

The selection of 5 and 9 hr for our manipulation follows parameters commonly utilized in the literature (Arnal et al., 2016; Belenky et al., 2003; Blagrove, Alexander, & Horne, 1995). It also limits the risk involved at the low end based on previous research lasting 7 days, which found that the minimum amount of sleep to maintain alertness and performance is 4 hr each night (Belenky et al., 2003). Participants were also repeatedly reminded of the clear option to withdraw from the study if the reduced sleep schedule resulted in a safety concern.

Interviews with each participant followed within 3 weeks of completion to identify additional details related to the impact of sleep on their perceived mental toughness. Interviews averaged 45 min in length, with a range of 35 to 50 min, and were recorded to allow for later transcription. The semistructured interview questions included those selected from a list of 10 preprepared questions, depending upon the results tied to each individual participant. The full list of questions is available as a supplementary file but included, "How did it feel to have more/less sleep than usual?", "What did you notice about your thoughts, feelings and behaviors when you had more or less sleep?", and "Looking at your pattern (see Figures 1 and 2 for examples, which was provided to interviewees in advance), any surprises?"

Data Screening and Analysis

We adopted a visual analysis procedure (Horner et al., 2005) and plotted individual participant scores for MTI and RCSQ over the 4 experimental weeks (Figures 1 and 2). We then utilized visual inspection to identify occurrence of effect. We also identified criteria for a meaningful minimal benefit and harm (Stoové & Andersen, 2003). To calculate these criteria, we utilized data from Gerber et al. (2012) and calculated the average differ-

Table 3
N-of-1 Description

Participant	Focus event	Brief description
Participant 1	800 m	47-year-old man racing 800 m—marathon
Participant 2	Middle distance	42-year-old female cancer survivor—range of events
Participant 3	Triathlon	49-year-old man racing 10K—triathlon
Participant 4	Marathon	50-year-old man racing 10K—marathon
Participant 5	10K	53-year-old man racing mile—marathon
Participant 6	Triathlon	55-year-old man racing 10K—triathlon

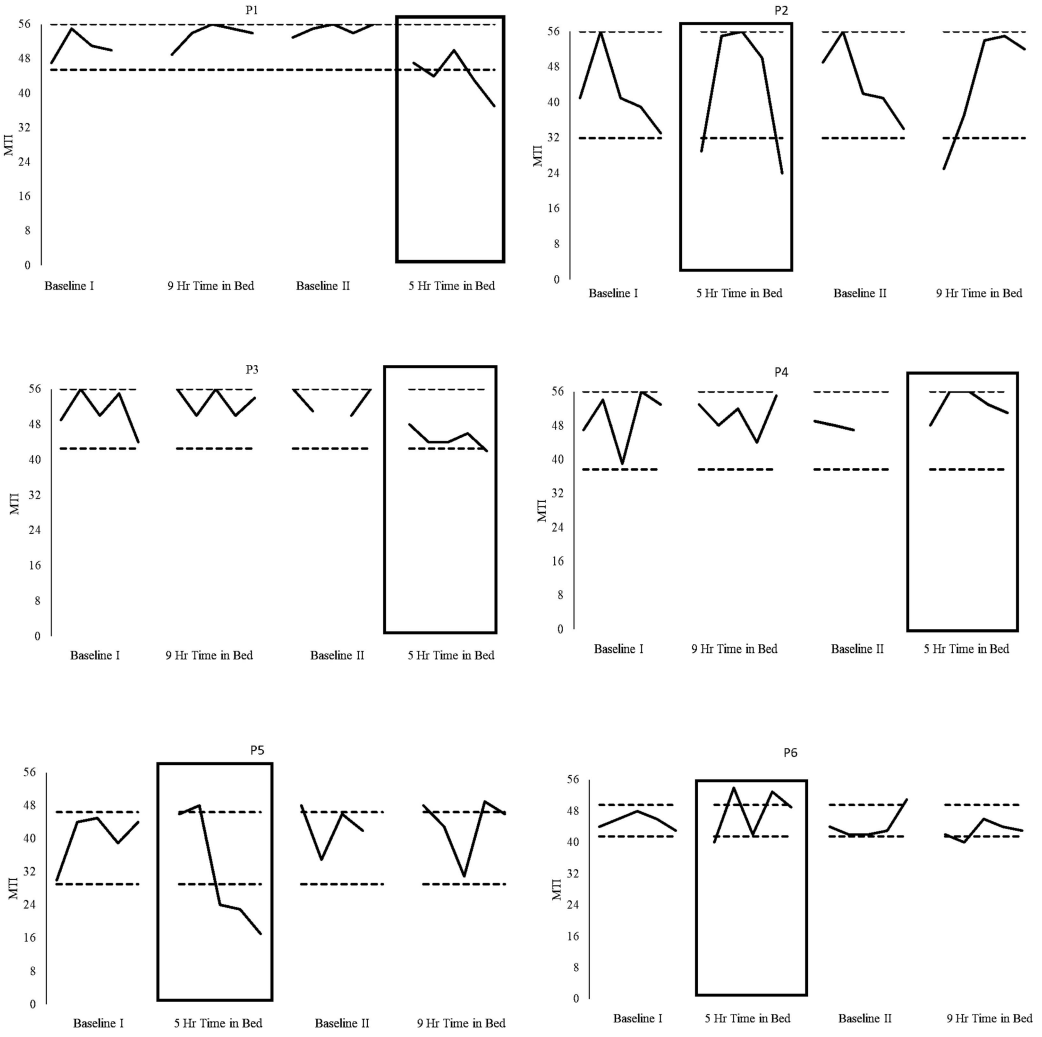

Figure 1. Mental Toughness Index assessment score to time-in-bed hours.

ential in percent from the mean in their study on exercise and mental toughness (which came to 3.3%). The meaningful minimal benefit and harm from the manipulation was then calculated from the absolute lowest and highest MTI scores over the 10 days of baseline ± this 3.3% differential. We used these criteria, modeled after Hrycaiko and Martin (1996), to determine the degree to which sleep had an influence on mental toughness. First, we looked for the presence of overlapping MTI data points at baseline compared with the treatment periods.

Second, we considered the magnitude of the change in MTI during treatment periods, noting that the range would be limited due to ceiling effects of MTI scoring. Third, we examined the trajectory of change in MTI over the treatment period (Jones, Lavallee, & Tod, 2011). Social validation interviews followed this inspection to evaluate the personal interaction with the intervention. Social validity has been suggested as a method of examining the importance of dependent variables to the participant and is a process by which the outcomes of behavioral research can be eval-

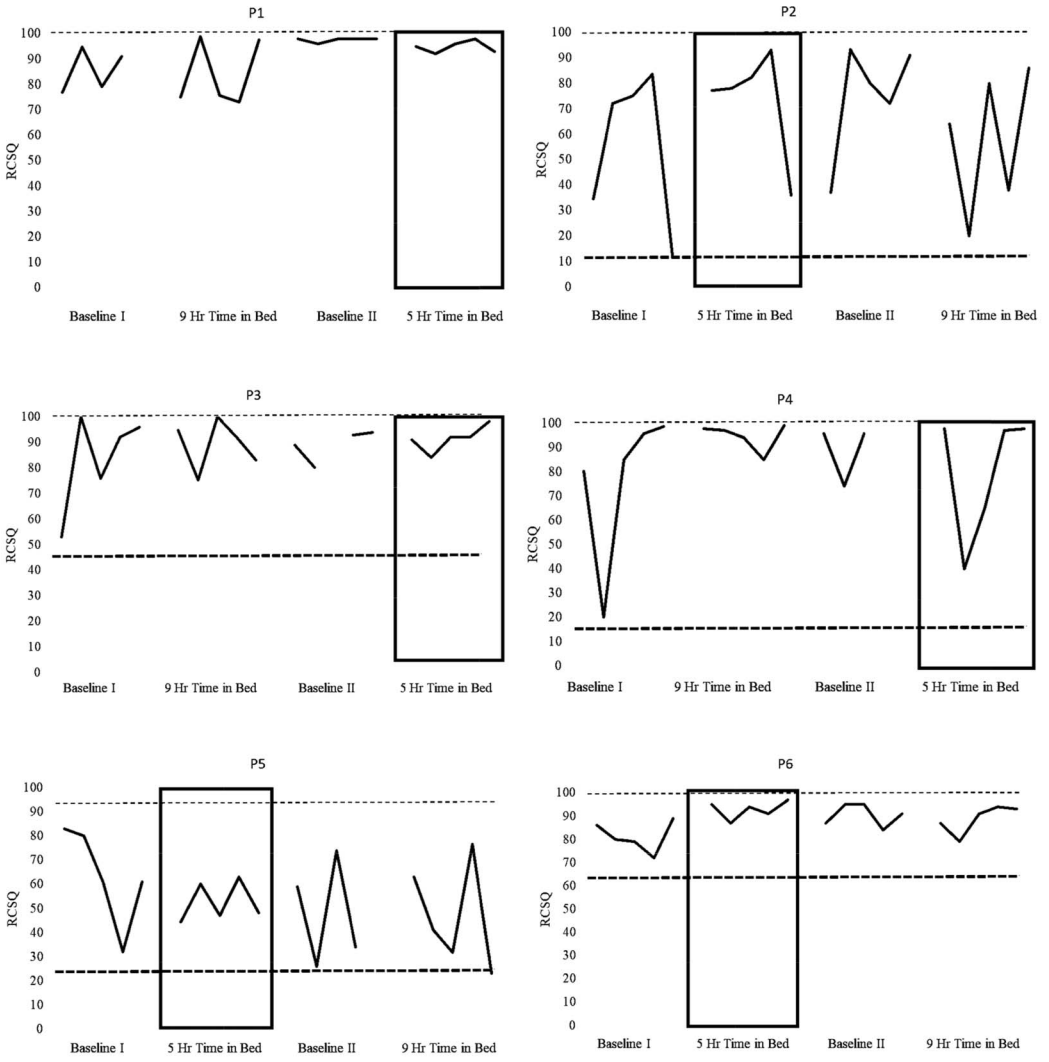

Figure 2. Sleep quality to time-in-bed hours.

uated (Wolf, 1978). In a review of 40 studies using single-subject design, 26 of them involved a formal social validity evaluation with participants (Martin, Thompson, & Regehr, 2004).

Results

Results for each of the six participants were analyzed, and summary graphs for the influence of time in bed on MTI and RCSQ scores are in Figures 1 and 2, respectively. An individualized discussion about each participant within this N-of-1 study is provided in the following text, followed by thematic coding of mental toughness influencers across the broader group. Sleep quality as measured by the RCSQ appeared to follow a pattern unrelated to time in bed (Figure 2). This may be due to the way in which the RCSQ measures quality of the sleep period (i.e., did individual fall asleep quickly, or did they wake during the night) rather than the perceived value of said sleep (i.e., did individual feel rested upon waking?). Conversely, analysis of MTI to time in bed on the final day of the reduced sleep time in

bed demonstrated a notable association in four of the six participants and thus became the focus of our qualitative interviews summarized in the discussion below.

Individual participants' insights.

Participant 1. Figure 1 shows that Participant 1 (P1) recorded the three lowest MTI scores, and five of his lowest eight scores from the entire study, during the 5-hr time in bed days. This did not meet the first two of our criteria for sleep influencing mental toughness (MTI on baseline days and 9-hr time in bed days must all exceed all 5-hr time in bed days). However, it did meet the third criteria (MTI on final 5-hr time in bed day must be equal to or lower than any other recorded day). P1 reported during the follow-up interviews that had the MTI assessment been performed in the midevening (when he remembered his mental toughness being at its lowest point) rather than the late afternoon, and his scores during that 5-day period would likely have been even lower. He noted that the 9-hr time in bed felt like normal to him, whereas the 5-hr time in bed "felt wrong." The interviews revealed a variety of secondary influencers utilized to buoy his MTI for both his professional and personal pursuits in the absence of sleep. He, like several of the participants, reported utilizing similar strategies to what he would use in an endurance event such as an Ironman triathlon or marathon. These included external support from family and friends, regular self-talk, nutritional focus, and overall mindset about why he was limiting his time in bed. Although he expressed a belief that these helped him throughout the 5-day period of 5-hr time in bed, he still demonstrated a notable reduction in overall MTI during this portion of the study. When asked specifically about his rebound (partially upward) on the third day of this period, he noted that his MTI felt like it dropped as the evening continued on:

> I made it through the day and by then [4 PM, when he would complete the MTI assessment], I was probably almost on the high of "that was ok—I made it. That's not that bad." Then later in the day it would have been down.

He also noted the cumulative deleterious effect on his MTI as the week continued: "What I found through the week of five hours (time in bed), I needed that sort of crutch each night more." This "crutch" was a reference back to some of the tools and strategies he had mentioned previously in the discussion and helped buoy his mental toughness levels.

Participant 2. Figure 1 revealed that Participant 2 recorded her single lowest MTI score on the final day of the reduced time in bed week. However, the remainder of her week did not appear to show an effect of reduced time in bed and MTI score. Her results adhered to our third criteria (MTI on final 5-hr day being lower than/equal to all other recorded days) but did not meet the first two (MTI on baseline days and 9-hr time in bed days must all exceed all 5-hr time in bed days). The follow-up interview provided insights into potential influencers of this outcome, as she expressed a preference for less sleep and a dislike of the 9-hr time in bed. She also noted being energized by the additional productivity during the 5-hr days, before her MTI dropped to its lowest level on the final day of that reduced time in bed week.

> I do better with less sleep than most people, so the decrease in sleep didn't upset me a whole lot other than being up earlier in the morning than I was used to . . . I was so productive during those [extra] hours!

In fact, she preferred the 5-hr to the 9-hr time in bed, which may be related to her low MTI score on the first day of the longer time in bed week:

> Being in bed for nine hours was really hard for me. I found that it was a struggle on a lot of levels. I do not mind the short nights as much as I do the long ones. On the nine hour nights, I'm throwing off things (schedule) and having to get to bed so early it took longer to fall asleep sometimes. Even if it didn't take longer, I didn't stay asleep as well. I'd be awake at 11 PM and again at 2 a.m.

Participant 3. Participant 3 demonstrated a pattern more closely related to P1, as his MTI scores on the 5-hr week represented five of the six lowest MTI scores from the entire 20 days of the study. He described his experience and general mental toughness during the 5-hr time in bed week as:

> That was evil. That thing kicked my butt by day two . . . It's amazing how that extra hour, hour and a half after a couple of days can start to wipe you out and it was a killer. That was a tough week.

However, due to 1 low MTI day scored during the initial baseline (which interestingly occurred on a night when sleep quantity was below his normal baseline), he only met the third criteria (MTI lowest on final day of the 5-hr

week compared with all other recorded) and not the first two. Participant 3's interview revealed that this overall drop in MTI across the 5-hr time in bed week occurred in spite of a very purposeful approach to the week including advanced planning, banking sleep, strategic activity, and other attempted influencers as noted here:

> [Strategies were] a key part of me still being successful in my job. I knew this was coming up and I had banked a little bit of sleep . . . Within the actual job I had things written out for the entire week—I had an outline of my week . . . and I structured the schedule knowing that this was coming.

The concept of banking sleep before sleep loss has been demonstrated to be an effective strategy to maintaining performance in the literature (Rupp, Wesensten, Bliese, & Balkin, 2009). He then expanded upon these strategies as follows:

> The mental preparation was "ok—I'm exhausted. It's only 7AM and it's not going to get better." I do not drink coffee or any of those stimulants . . . so it was just consciously looking at and having the expectations that I was going to be a little more tired, a little bit more rundown and that I still had 8 hr of work ahead of me here at the job and to taper that out. As opposed to coming in guns ablazin' on-fire energy . . . It's almost like a triathlon. Instead of doing a sprint (short—one hour event), I did an Ironman. I was just as tired at the end of the day as I would have been on the sprint, but I just had to spread out the effort.

Participant 4. Participant 4 (P4) was one of two participants who demonstrated limited impact of time in bed on MTI scores and did not meet any of the three criteria set forth as demonstrating sleep as a primary influencer of MTI. In discussing the week involving the reduced time in bed hours, he credited the primary buoy of mental toughness while accessing limited sleep as being his work setting during that week, which he described as follows:

> I was in New York City and we were presenting to a lot of the big banks on Wall Street . . . Some of this [higher MTI] might be the adrenaline of "Hey—I'm going in tomorrow morning to present to JPMorgan Chase."

He repeatedly conveyed during the interview that the intensity of that week provided additional energy that helped him overcome his limited sleep schedule.

Participant 5. Participant 5 (P5), the fastest elite runner of the group who is also on an elite-level career path, started the week off with high MTI the first 2 days of the limited time in bed week and thus did not meet the first two criteria. However, during the final 3 days of this week, his MTI scores showed a notable drop and a clear adherence to the third criteria. He described the 5-hr week as follows:

> It was probably one of the hardest things I've done . . . I would much rather run a workout where I make myself puke than go without sleep like that. The first day or two I was thinking "ok—I can make this happen—I can survive." Then I really actually quite frankly considered bagging it (the study).

Similar to three of the other participants, he integrated multiple strategies—some being the same strategies he utilizes as an athlete to buoy his mental toughness throughout the week:

> I would say it [strategies were] similar thing I do during the course of a workout where things aren't going well and you do not feel right. It's easy to run a workout when you're feeling good and it's easy and the workout's within your capability. But it was one of those things where it felt somewhat outside of my capability and comfort zone and so I used some of the similar techniques in terms of just internal conversations with myself to get my ass moving to the point where I could still get the work done I needed to get done . . . that's where I just tried to pull off of what I use during the course of those workouts where I just kind of refocus and have those internal conversations with myself.

Participant 6. Participant 6 demonstrated results similar to P4 and did not meet any of the three criteria set out in this study for sleep as the primary influencer of MTI. Interestingly, during the qualitative portion of the study, he identified a similar buoy of his mental toughness during the reduced time in bed week as P4. He described the week in this way:

> I work as a consultant and my company was responding to an RFP (proposal). We put together what's called "The Pursuit Team" and I was pulled into the Pursuit Team and flown out to Pennsylvania to work on our response . . . They're high energy, they're long days, they're go-go teams and it just happened to be during the five hour week. We were pulling 18 hr in the office anyway, so it was a fast, high-energy week trying to get the response out which made the fives so much easier because there's a group of people who are doing the exact same thing.

Similar to Participant 2, Participant 6 also expressed enjoying the increased productivity of the 5-hr week and also related his consistent short-term MTI on reduced sleep to his identity growing up swimming and delivering newspapers:

> My background is swimming in high school and college. Morning practice starts at 5 a.m. and so getting up early isn't difficult. I had eight years of conditioning of doing that and so that's still there: the 'get up early—go do something'. . . I used to (as a kid) deliver papers and you've got to get up in the morning, get those papers out because people were calling at 6 a.m. asking where their paper is . . . So, on the five hours it was still the same thing: look at the clock, it says 3 a.m. 'Ok—it's time to get up' and I usually beat my clock (alarm) even on those 5 hr [days].

Discussion

The purpose of this experiment was to examine the effect of time in bed extension and restriction on mental toughness and sleep quality. In line with the results of Study 1, we found that sleep duration is related to changes in mental toughness in some participants but not all. Restricted time in bed appears to affect MTI, especially at the end of a 5-day period. However, given the inconsistency of change in mental toughness during the treatment periods, it is evident that sleep duration is not the only construct that influences MTI score. Sleep duration is related to mental toughness in some people, but the effect was not as pronounced as hypothesized. In addition, despite the correlation between quality and duration in Study 1, we found that time in bed did not influence the sleep quality score when recorded using the RCSQ assessment.

General Discussion

The purpose of this study was to explore the direction and magnitude of the relationship between sleep (duration and quality) and mental toughness and to examine the effect of time in bed extension and restriction on mental toughness. The results of Study 1 revealed moderate-sized positive relationships between sleep quality and mental toughness and sleep duration and mental toughness; however, the regression results revealed that only sleep quality predicted MTI score (at the $p \leq .05$ level). Study 1 also revealed that the magnitude and direction of the relationship between sleep duration and sleep quality is moderate and positive and is significant at the $p \leq .001$ level. The lack of an additional significant regression may be explained by a range of potential mediating variables. These include but are not limited to the ceiling effect with mental toughness and athletes (Zeiger & Zeiger, 2018), as this would effectively cap the available improvement with an increase in sleep above the mean. Although not all participants in Experiment 1 would define themselves as "athletes," all participants were required to be exercising a minimum of three times per week. In addition, perhaps the "sweet spot" for sleep also has implications for the impact on mental toughness outside of the midrange of a 7- to 8-hr time in bed. Or potentially, the cumulative effect of sleep restriction beyond a single day (Van Dongen, Maislin, Mullington, & Dinges, 2003) would reveal specific variables with the greatest influence on mental toughness.

The results of Experiment 2 revealed that manipulating time in bed did not meaningfully influence the state-like variability of mental toughness (Gucciardi et al., 2015) across all participants. Similarly, sleep quality also did not influence mental toughness to the extent that we expected. Follow-up interviews highlighted some of the reasons that restricted and extended time in bed did not consistently influence their perceived mental toughness, as multiple participants pointed to additional influencers that helped them buoy or at least limit the drop in mental toughness when sleep was limited. These included general mentality about sleep, purposeful strategies to elevate mental toughness throughout the day, foundational well-being elements (hydration and enhanced nutrition), and advanced personal planning (Cooper et al., 2019). Two of the participants also noted that the reduced sleep weeks coincided with high adrenaline weeks professionally, which they both indicated may have provided a similar buoy to their mental toughness scores during that period.

Variability of mental toughness was also revealed as a result of this study. This evidence supports the state-like nature of the state-trait construct previously noted in the literature (Cooper, Wilson, & Jones, 2018). It is notable that we initially recruited six participants for this N-of-1 study with the expectation that due to the requirements, a significant percentage of the participants might choose to drop-out (Fukuoka, Gay, Haskell, Arai, & Vittinghoff, 2015; Stubbs et al., 2016). However, all six of the initial participants completed the full study, which may reflect the connection between men-

tal toughness and intention previously identified (Gucciardi, 2016).

Strengths and Limitations

This study provided a real-life basis from which to examine the influence of sleep on mental toughness. However, we did not measure behavioral consequences of sleep (e.g., changes in athletic performance), nor did we examine a potential influence of ego depletion (Baumeister, Vohs, & Tice, 2007) or the connection of mood to the executive functions necessary to complete the questionnaire (Carvalho & Ready, 2010). In addition to measuring changes in mental toughness, researchers could also measure changes in human performance (e.g., time to exhaustion and psychomotor vigilance) to see whether the relationship between sleep and mental toughness is meaningful rather than an epiphenomenon. The inclusion of elite but not professional masters athletes provided grounding more closely related to the general population in terms of the realities of life (careers, children, bills, and other external stressors) as compared with students or professional athletes. Also, none of the Experiment 2 participants had young children, resulting in the elimination of one sleep variable common to the general population. In addition, the inclusion of only athlete participants also likely resulted in a higher mental toughness baseline and a smaller mental toughness variability (Zeiger & Zeiger, 2018), and it would be interesting to compare these results to less serious athletes in future studies. Finally, the N-of-1 longitudinal design of this study, although not intended to identify population parameters, does set the stage for effective real-world analysis (Johnston & Johnston, 2013).

Using time in bed as a proxy for sleep duration is not without its limits. In particular, during the 9-hr time in bed weeks, participants reported difficulty with going to bed early, indicating the longer time in bed did not translate directly to sleep duration. Our choice of the RCSQ to assess sleep quality was an effective tool for the initial experiment and 3 (Baseline I and II and the 9-hr time in bed) of the 4 weeks of the N-of-1 experiment. However, due to the focus of the RCSQ on the quality of the available sleep rather than total sleep, it was not an effective assessment for the 5-hr time in bed week. In addition, we learned during that the timing of our late afternoon (generally as work was ending), MTI assessment was not optimal and may have been more accurate if completed in the late evening.

Future Directions

This study sets the stage for additional future investigation into the influence of sleep on mental toughness and strategies utilized by individuals to sustain or further build mental toughness. Experiment 1 shows that sleep quality is important. The way in which that quality is enhanced could take a number of directions in future studies and may also build on the time in bed (sleep quantity) component. If we were to purposely manipulate sleep quality through the enhancement of sleep hygiene, time leading up to sleep and purported sleep-enhancement tools such as sound machines, additional insights might be gleaned. Or, perhaps varying sleep based on a standard deviation from the participants' average sleep time (rather than a set time in bed of 5 and 9 hr) would have revealed differing insights. Measuring sleep with more accurate tools such as polysomnography may provide insights into how other sleep-related variables such as sleep onset latency and time in bed are related to mental toughness (Clark & Landolt, 2017). The resources caravan concept suggests that as one resource goes up, so do others. However, it may be the case that sleep positively influences some dimensions but degrades others. For example, an individual might have better emotional regulation because of REM sleep but may recruit fewer additional mental toughness buoys due to a feeling of guilt for wasting time in bed. Expanding from the N-of-1 design to look at within-person changes in mental toughness and sleep across a broader population would be of value to expand upon this initial research. Further, the need for (or perceived need for) mental toughness was noted as being increased among our study participants during their low time in bed days. In moving outside of the athletic (or at least the elite athletic) population, there would be value in determining how often during a typical day an individual outside of a sporting or military setting recognizes the need for mental toughness and how often they choose to utilize it to achieve the stated goal and the outcome of doing so. Fi-

nally, additional opportunities exist in examining some of the other mental toughness influencers noted in this study and how individuals and practitioners can incorporate those into their approaches.

Conclusion

The purpose of this two-part study was to explore the direction and magnitude of the relationship between sleep (duration and quality) and mental toughness. Part 1 of this study revealed that sleep duration and sleep quality are related to mental toughness; however, the nature of the relationship is complex (i.e., mediation, moderation, and suppression). Experiment 2 revealed that restricted time in bed (i.e., restricted sleep duration) influenced mental toughness in some participants, but not others, and largely had no meaningful effect on sleep quality. Experiments 1 and 2 provide grounds for future research in this area. For example, in addition to sleep, researchers may also consider other antecedents of mental toughness that practitioners can manipulate.

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