The impact of sleep on mental toughness: Evidence from observational and N-of-1 manipulation studies in athletes

Abstract

The purpose of this 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. Study 1 was a cross-sectional observational study examining the relationship between sleep quality and duration (hours) and mental toughness in 181 participants. Winsorized correlations revealed both sleep duration (ρ_w = .176 [.033, .316], p = 0.016) and quality (ρ_w = .412 [.270, .541], $p \leq .001$) were associated with mental toughness. Follow-up regression analyses revealed that 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, but with six participants to further examine whether manipulated time in bed (i.e. sleep duration) consistently influenced mental toughness. Participants recorded sleep quality, duration, and mental toughness over the five weekdays during two separate two-week periods of baseline (normal sleeping pattern) followed by manipulated time in bed (counterbalanced 9 hours or 5 hours). Visual analyses (including determination of non-overlapping data points between baseline and intervention weeks) revealed reduced time in bed negatively impacted the mental toughness of four 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 as were the identification of potential buoys of mental toughness in the absence of sleep.

Key Words: Sleep, Mental Toughness, Masters Athletes, *N*-of-1, Sleep Duration

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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. If mental toughness is a state-like construct (Gucciardi et al., 2015), then research is warranted that explores the potential antecedents of changes in mental toughness across different states. Given the broad literature that reveals positive relationships between sleep quality and duration, and several components of mental toughness (e.g., attention; Lim & Dinges, 2008, and emotional regulation; Baum et al., 2014) we contend that both are potentially relevant antecedents of mental toughness that warrant further exploration.

There is ample evidence regarding the effects of sleep manipulation on physical and cognitive performance (e.g., Psychomotor vigilance: Belenky et al., 2003) as well as psychological function (e.g., social and emotional function: Goldstein & Walker, 2014). For example, mood, attentional control, and emotional regulation are shown to covary with sleep duration (Krizan & Herlache, 2016) and quality (Tempesta, Socci, De Gennaro, & Ferrara, 2018). An increase or decrease in sleep is also involved in the regulation of pain, with threshold tolerance decreasing following one night of sleep deprivation (Onen, Abdelkrim, Gross, Eschallier, & Dubray, 2001), or following partial sleep restrictions (Haack, Sanchez, & Mullington, 2007).

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 resources that interweave to drive performance. These individual resources (e.g., emotional regulation, self-efficacy, optimism, attention regulation; Stajkovic, 2006) are tied together so people high in one are usually high in others. Given the range of studies that reveal 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 mental toughness, 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) 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. 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 sub-dimensions. 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 One

Methods – Experiment 1

Participants

Following ethical approval from the first author'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 email 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, 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.

Measures

Sleep. Sleep duration was based on self-reported time in bed to the nearest 0.5 hour (e.g., Brand et al., 2014). Sleep quality was assessed using the Richards-Campbell sleep questionnaire because it provides an effective assessment of the prior night's sleep (Hoey, Fulbrook, & Douglas, 2014). The Richards Campbell Sleep Questionnaire (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 or MTI (Gucciardi et al., 2015) an eight question, seven-point Likert scale self-assessment, was utilized to assess mental toughness. It prompts participants to indicate the accuracy a specific statement, ranging from one

(*100% False*) to seven (*100% True*). Total scores range from 8-56 with higher scores indicating higher mental toughness and has been shown (Gucciardi et al., 2015) to be reliable (p = 0.860 to 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 Mental Toughness Index at approximately 16:00 as a review of their MT for that specific day) on one of five week days (Monday – Friday) and received an email 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.

Results- Experiment 1

Data Screening and Analysis

Data analysis was performed utilizing R (available in the supplementary material). We examined the data for the assumptions of ordinary least squares regression (normality of residuals, outliers) and found univariate outliers for both sleep quality and sleep duration. A decision was made to retain the outliers as 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 [LLCI, ULCI] and robust regression (Wilcox, 2017) using a maximum likelihood estimator. Next, we calculated descriptive statistics and calculated internal reliability estimates from the MTI and RCSQ scores (see Table 2). Finally, our Winzorized correlational analyses demonstrated that both sleep duration (ρ_w = 176 [.033, .316], p = 0.016) and quality (ρ_w = .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 (See Table 3).

Discussion Experiment One

This initial study 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 & Fidell, 1996 suggest that a significant correlation and a non-significant 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).

Our second study 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 (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 study one 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.

Methods – Experiment 2

Design

We adopted principles and practices associated with an *N*-of-1 study model (McDonald et al., 2017; Vieira et al., 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 in order 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 1 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 drop-out 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 hour), Mental Toughness Index (MTI) and Richards Campbell Sleep Questionnaire (RCSQ) were utilized in the same format as Experiment 1.

Procedure

Participants completed five days (Monday through Friday during the selected week) of baseline assessments, which included recording their sleep duration from the previous night to the nearest 0.5 hours and sleep quality using the RCSQ in a morning self-assessment. They then completed a mental toughness assessment using the MTI at approximately 16:00 each day. The sleep schedule during this initial five day period was self-selected by the participants. During week two, the first of two sleep opportunity manipulation weeks, the six participants were randomly assigned to either a five hour or nine hour time in bed manipulation schedule (three people assigned to each group). Participants completed the same morning and afternoon self-assessments as the baseline week (also Monday through Friday). Following a four 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 (five or nine hours).

The selection of five and nine hours 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 four

hours 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 three weeks of completion to identify additional details related to the impact of sleep on their perceived mental toughness. Interviews averaged 45 minutes in length with a range of 35-50 minutes and were recorded to allow for later transcription. The semi-structured interview questions included those selected from a list of ten pre-prepared questions, depending upon the results tied to each individual participant. The full list of questions is available as 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, 2005), and plotted individual participant scores for MTI and RCSQ over the four experimental weeks (See 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 (2012) and calculated the average differential in percent from the mean in their study on exercise and mental toughness (which came to 3.3%). The meaningful minimal benefit and harm 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, 2016). Social validation interviews followed this inspection to evaluate the personal interaction with the intervention. Social validity has been suggested (Wolf, 1978) as a method of examining the importance of dependent variables to the participant.

Results – Experiment 2

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 below, 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 (see 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, the end of week MTI to time in bed analysis 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 one (P1) recorded the three lowest MTI scores, and five of his lowest eight scores from the entire study, during the five-hour time in bed days. This did not meet the first two of our criteria for sleep influencing mental toughness (MTI on baseline days and nine-hour time in bed days must all exceed all five-hour time in bed days). However, it did meet the third criteria (MTI on final five-hour 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 mid-evening (when he remembered his mental toughness being at its lowest point) rather than the late afternoon, his scores during that five-day period would likely have been even lower. He noted that the nine-hour time in bed felt like normal to him while the five-hour 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. While he expressed a belief that these helped him throughout the five-day period of five-hour time in bed, he still demonstrated a notable reduction in MTI overall 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 two (P2) recorded her single lowest MTI score on the final day of the five 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 five-hour day being lower than/equal to all other recorded days) but did not meet the first two (MTI on baseline days and nine-hour time in bed days must all exceed all five-hour time in bed days). The follow-up interview provided insights into potential influencers of this outcome, as she expressed a preference for less sleep, a dislike of the nine hour time in bed days and noted being energized by the additional productivity during the five hour 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 five hour to the nine-hour 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 don't 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 AM.

Participant 3 (P3) demonstrated a pattern more closely related to P1, as his MTI scores on the five-hour week represented five of the six lowest MTI scores from the entire twenty days of the study. He described his experience and general mental toughness during the five-hour 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 one 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 five-hour week compared to all other recorded) and not the first two. P3's Interview revealed that this overall drop in MTI across the five-hour 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 prior to 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 with:

> The mental preparation was 'ok – I'm exhausted. It's only 7AM and it's not going to get better.' I don't 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 hours 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 (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 the following:

> 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 (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 two days of the limited time in bed week and thus did not meet the first two criteria. However, during the final three days of this week, his MTI scores showed a notable drop and a clear adherence to the third criteria. He described the five hour week as:

> 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 don't 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 Six (P6) 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 hours 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 P2, P6 also expressed enjoying the increased productivity of the five hour week but 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 AM 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 AM asking where their paper is… So, on the five hours it was still the same thing: look at the clock, it says 3 AM. 'Ok – it's time to get up' and I usually beat my clock (alarm) even on those 5 hour [days].

Discussion – Experiment Two

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 one, 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 five-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. Additionally, despite the correlation between quality and duration in study one, 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 one 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 one 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. While not all participants would define themselves as "athletes," all participants were required to be exercising a minimum of three times per week. Additionally, perhaps the "sweet spot" for sleep (Khatib et al., 2018) also has implications for the impact on mental toughness outside of the mid-range of seven to eight hours' 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 study two revealed that manipulating time in bed did not meaningfully influence mental toughness nor sleep quality across all participants 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 wellbeing elements (hydration and enhanced nutrition) and advanced personal planning (Cooper et al., 2019)

Variability of mental toughness was also revealed as a result of this study. This evidence supports the state-like nature of the 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 % of the participants might choose to drop-out (Fukuoka, Gay, Haskell, Arai, & Vittinghoff, 2015; Stubbs et al., 2017). However, all six of the initial participants completed the full study, which may reflect the connection between mental 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). In addition to measuring changes in mental toughness researchers could also measure changes in human performance (e.g. time to exhaustion, 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 to students or professional athletes. 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). Finally, the *N*-of-1 longitudinal design of this study, while 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-hour 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 three (Baseline I, II and nine hour time in bed) of the four 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 five-hour time in bed week. Additionally, 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. Study one shows that sleep quality is important. 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. 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 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 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 do they choose to utilize it to achieve the stated goal and the outcome of doing so. Finally, 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 one 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, suppression). Study two 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. Studies one and two 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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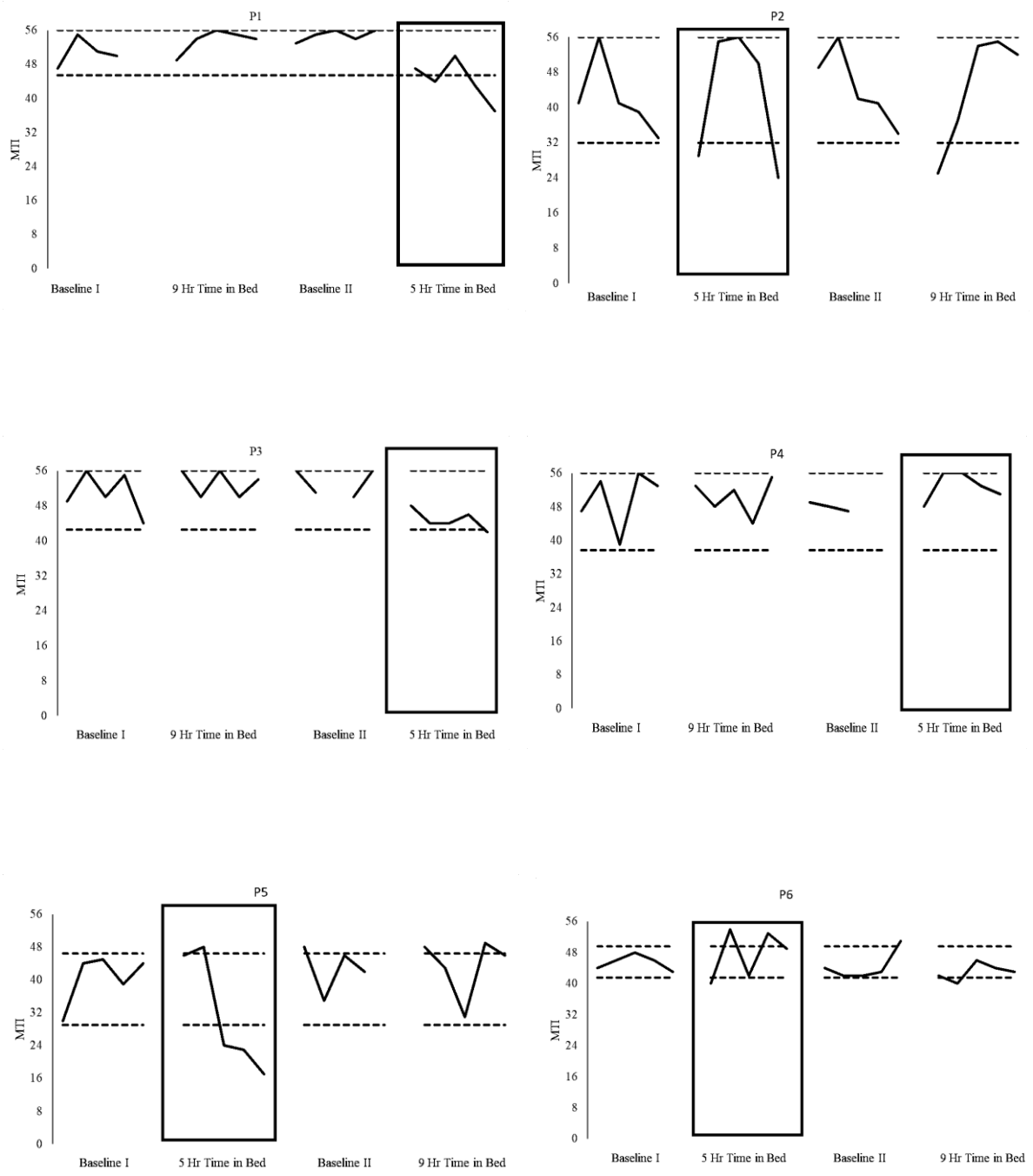
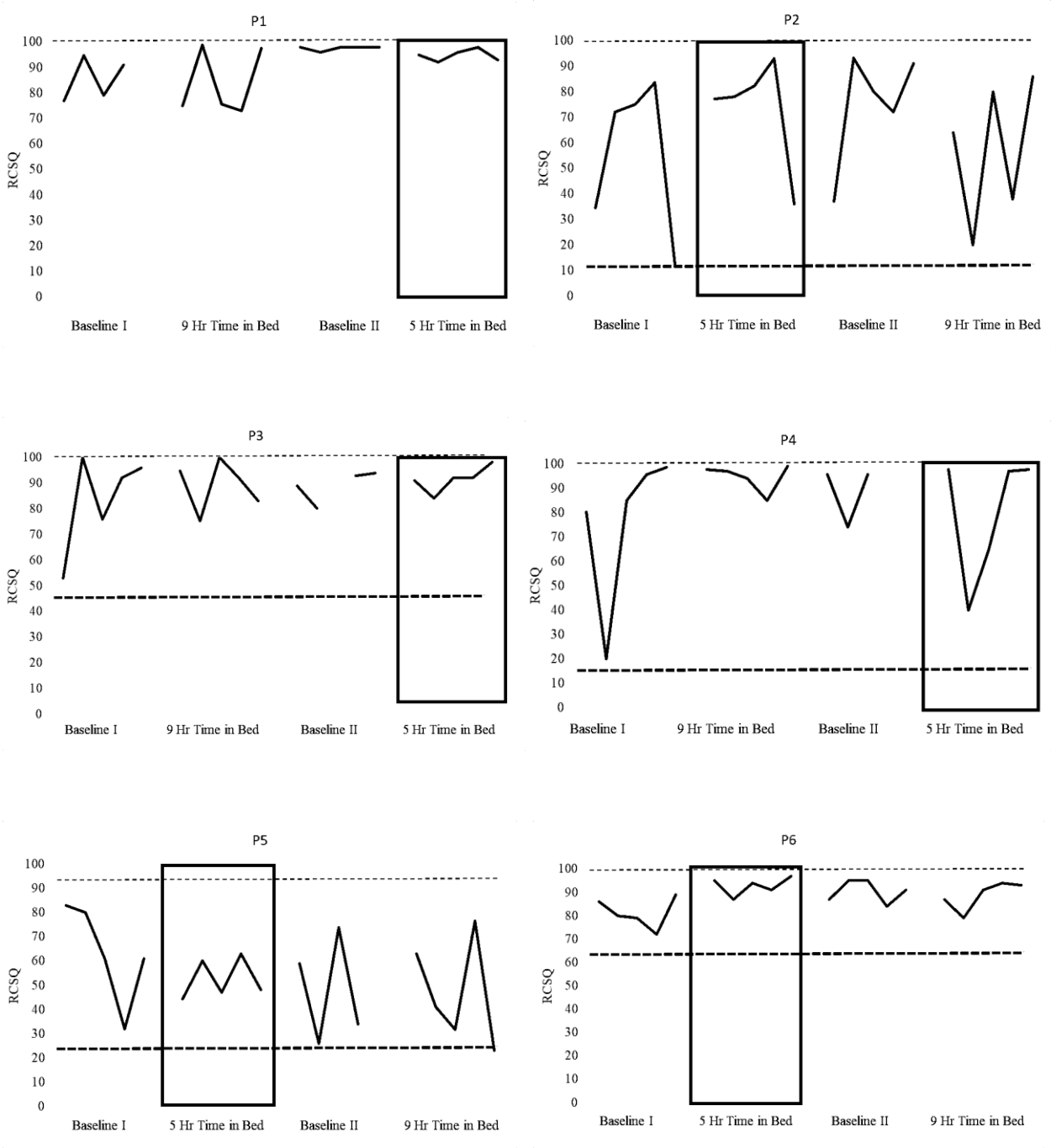
Figure 1: Mental Toughness Index assessment score to Time in Bed hours



Note: Boxed section show the 5 hour time in bed treatment. Baseline represents self-selected time in bed.

Figure 2: Sleep Quality to Time in Bed hours



Note: Boxed section show the 5 hour time in bed treatment. Baseline represents self-selected time in bed.

Table 1:

N-of-1 Description

Participant	Focus Event	Brief Description
P1	800M	47 year old male racing 800M – Marathon
P2	Middle Distance	42 year old female & cancer survivor - range of events
P3	Triathlon	49 year old male racing 10K - Triathlon
P4	Marathon	50 year old male racing 10K – Marathon
P5	10K	53 year old male racing mile - Marathon
P6	Triathlon	55 year old male racing 10K - Triathlon

Table 2

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

	Mean	Median	*SD*	Winsorized Mean	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 3:

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_w [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], $p = 0.016$		0.450	[−0.3254, 1.22]	0.395	1.139	.256
S.Quality	.412 [.270, .541], $p \leq .001$	.403 [.269, .524], $p \leq .001$	0.177	[0.117, 0,238]	0.030	5.738	≤ .001

Note: Winsorized correlation = ρ_w with 95% Confidence intervals based on 10000 bootstrapped sample and 20% Winsorizing, *b* = unstandardized regression coefficient, *CI* = confidence interval, LLCI = lower level confidence internal, ULCI = Upper level confidence interval, *SE* = standard error for the unstandardized regression coefficient, *p* = probability value