Exploring the Feasibility and Applicability of Whoop Technology in NCAA D1 Collegiate Wrestlers: A Pilot Study

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ABSTRACT

Although athletes decide to go to college ultimately to get an education, the importance of athletic performance to D1 college athletes and coaches cannot be looked over. Coaches and athletes across the country are looking for the most effective way to prepare and train to optimize athletic performance. New technology such as Whoop wearable devices, are leading the way, helping athletes optimize training and recovery to increase athletic performance. The main purpose of this pilot study was to explore the feasibility and applicability of Whoop technology in D1 college wrestlers. Specifically, the aims were to look at relationships between different Whoop biofeedback indicators and relationships between Whoop indicators and variables such as mood states, hydration status, and vertical jump height as a measure of performance. 9 male D1 college wrestlers (age: 21.2 $\pm$ 1.20) wore a Whoop strap every day and night except during competition, for 6 weeks during in-season training. The Whoop strap measured recovery percentage, heart rate variability (HRV), resting heart rate (RHR), sleep, and strain (from training and other physical demands) daily. Participants also completed the profile of mood states (POMS) questionnaire and a vertical jump test once weekly. At the conclusion of the study, participants completed the BEVQ-15 survey indicating their fluid intake habits over the course of the previous 30 days. At the conclusion of the data collection phase, 9 out of 10 participants had enough viable data to use for analysis. Additionally, multiple participants reported that they still use the Whoop device even after the conclusion of the study to continue managing their training and recovery. A 90% compliance rate and continued use of the Whoop technology points to its feasibility and applicability for college wrestlers. Results found that recovery, as measured by the Whoop, was positively associated with HRV and sleep, but negatively associated with RHR ($p<0.0001$, $p<0.0001$, and $p=0.003$ respectively). HRV was also found to be negatively associated with RHR ($p<0.0001$). Daily strain was negatively associated with sleep, RHR, and vertical jump height ($p=0.021$, $p=0.0002$, and $p=.037$ respectively). Lastly, sleep was positively associated with RHR ($p=0.041$). To add, there were no significant correlations between mood states as measured by the POMS as well as hydration status, with performance as measured by the vertical jump test. In conclusion, Whoop technology was found to be a feasible tool to use to measure performance and readiness biofeedback indicators in a small sample of D1 collegiate wrestlers and the usefulness of Whoop technology to help athletes and coaches make training adaptations and increase performance is promising.

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INTRODUCTION

Playing a sport at the Division 1 collegiate level is extremely demanding both physically and mentally. At this level, the game is taken very seriously and performance expectations from the coaches, institution, and players are also high. Because athletes, and wrestlers especially, hold themselves to a high standard, their performance and therefore ways to increase their performance are important to them. Additionally, because wrestlers must make a specific weight before each competition, they are often balancing training, rapid weight loss, and recovery. In fact, rapid weight loss in collegiate wrestlers before competition has been found to cause physiological impairments and distinct transient mood reductions (Choma et al., 1998).

Whoop is a relatively new biofeedback technology that gives athletes feedback on optimal sleep and readiness to train information. Whoop technology measures recovery using measurements of heart rate variability (HRV), resting heart rate (RHR), respiratory rate, sleep duration, and more (Whoop, 2023). One of the main questions of interest is to determine if Whoop devices are feasible and useful for athletes and college wrestlers specifically. Division 1 wrestlers train at a high level and require the best recovery possible to compete at their best. This is why it is important to understand if wearable technology like Whoop is a good tool to use to manage training and recovery.

Although sleep is often recognized as an essential component of recovery from exercise, assessments of sleep quality in competitive athletes shows a significant prevalence of poor sleep quality (Bird, 2013). In a study done by Dr. Walters of Wheaton College, sleep-deprived athletes consistently showed reductions in cognitive and motor performance, reaction times, and emotional stability (Walters, 2002). Inadequate sleep can have notable effects on health and athletic performance especially in competitive athletes and those at risk of overtraining. While sleep has been shown to impact athlete’s training, performance, and recovery, associations between sleep and specific physiological impairments are not as clear. In a study done on female collegiate cross-country athletes, Sekiguchi et al. (2019) investigated associations between heart rate variability, resting heart rate, and sleep characteristics (Sekiguchi et al., 2019). Results showed that resting heart rate was significantly higher and heart rate variability was significantly lower at the end of the season compared to the beginning, which was associated with increased in deep sleep stages (Sekiguchi et al., 2019). This might suggest that as the demand for recovery was higher due to the persistent demands of training, time asleep was also increased to help aid the recovery process. The implications of these studies are important for understanding the impact that sleep has on an athlete's recovery and identifies factors that impact the quality of sleep that athletes get. With that, further exploration of these areas deserves to be studied. Additionally, although some recommendations for increasing sleep quality for competitive athletes have been studied, more attention needs to be brought to specific lifestyle changes that can be made to help improve sleep quality.

One of the leading research questions for this study is to investigate the effect of hydration on HRV, strain, recovery, and athletic performance. Hydration plays a crucial role in our body’s ability to function normally. More than in non-athletes, collegiate athletes need to be even more thoughtful about their fluid intake because of increased physical exercise, travel, and other demands. Wrestlers, specifically, lose excess water weight in the days leading up to competition which often leads to acute dehydration (Pettersson & Berg, 2014). Wrestlers and other combat athletes routinely make weight the night before or the day of their competition. Pettersson and Berg (2014) investigated the prevalence of hypohydration on the day of competition of athletes in four different combat sports. In athletes who had morning weigh-ins, the prevalence of hypohydration was 89% among combat athletes (Pettersson & Berg, 2014). This evidence suggests that athletes, and wrestlers in general, need to be aware of their hydration status during training and before competition to ensure their performance and their health. An assessment of fluid intake habits and hydration status is needed to help wrestlers keep track of their fluid intake which is why the BEVQ-15 questionnaire is a great tool.

Athletes tend to show and withstand a wide variety of emotions during their competitive career. The mood or emotional state of an athlete can often determine their athletic performance and vice versa. It is not always easy to measure, or let alone understand, the psychology of athletes, but it is something that researchers have studied closely over the last couple decades. A study that looked at mood states of athletes used the POMS inventory as predictor of athletic performance among male cross-country runners (Cockerill et al., 1991). Race times of runners were plotted against each of the mood factors in the survey. Using a multiple-regression model from data from race one, Cockerill et al. were able to predict the order of finishers for the second race based on the interdependence of tension, anger, and depression as reported from the POMS ($P<0.01$) (Cockerill et al., 1991). It was noted that depending on sport, where physical and mental demands are different, other modes of mood identification might be necessary. Understanding mood disturbances and their impact on athletic performance is still highly debated. This is why another purpose of this study is to investigate the transient mood states of Division 1 college wrestlers and their impact on performance.

The main purpose of this study is to measure performance and readiness indicators of Division 1 NCAA collegiate wrestlers during a 6-week period in season while training and competing. The specific aims of the study are: 1. Assess the feasibility of using Whoop technology in NCAA D1 Wrestlers to assess Whoop collected data changes over the course of the season, 2. Determine whether strain and recovery as measured by Whoop, are correlated with performance, self-perceived fatigue, and hydration status, and 3. Determine if Heart Rate Variability is correlated with sleep, hydration, performance, and other Whoop measurements such as recovery, HRV, RHR, hours of sleep, sleep need, daily strain, and % of strain accounted for from workouts.

LITERATURE REVIEW

Population

Wrestlers are a unique breed of athletes. The sport is extremely dynamic and there are many factors that go into their athletic performance. An interesting part of wrestling is that it is a weight class sport which means wrestlers must weigh in at or below a specific weight before each competition. This aspect of the sport is important to make it as fair as possible, but it also comes at a cost. Some wrestlers find themselves having to lose up to 10% of their body weight weeks before the competition (Selvaraj, 2021). The term "cutting weight" is often used to describe the rapid weight loss that comes from fluids to allow them to compete at their weight class. This not only has impacts on their performance but on their overall health as well. Hydration has serious implications for health and athletic performance. A review by Judelson et al. (2007) found that hypohydration, or dehydration, decreased overall strength by 2%, power by 3%, and high-intensity endurance by ~10% (Judelson et al., 2007). Further, a study done by Buford et al. (2006) investigated the effects of a collegiate wrestling season on body weight, hydration, and muscular performance (Buford et al., 2006). Findings showed that muscular performance was increased by the college wrestling season as the ratio of peak torque-to-body weight ratio increased significantly. Since weight management is an important aspect of wrestling, wrestlers often look for the easiest way to lose weight which is typically by losing water weight. Although this is a quick way for wrestlers to shed 3-5 pounds it is not sustainable and often leads to performance decline. It is widely understood in the wrestling community that proper hydration is important for athletic performance but often coaches preach that water breaks aren't necessary and continue to put wrestlers through grueling workouts without water for extended periods of time. This is not only a bad habit to create for their performance but a bad habit to reinforce for the rest of their lives. An article from USA Wrestling, and experts in the field, explain that our bodies are 50-65% water. Especially in a lean population such as wrestlers, water is essential to bring oxygen and nutrients to our working muscles but also to take heat and toxins away (Krumrie, 2013). Additionally, the college wrestlers who participated in this study were deemed dehydrated both during the competitive season and postseason (Buford et al., 2006). This further identifies the negative effects weight management and dehydration has on overall strength and in turn, performance.

Hydration

Dehydration is a serious issue in athletes and regular exercisers. Dehydration impairs the body’s ability to thermoregulate and maintain water balance during exercise (Hillyer et al., 2015). Dehydration also impairs cognitive function because water is the vehicle by which nutrients and oxygen get to the brain. Research tells us that 2% of body mass loss from fluids is enough to impair exercise and athletic performance (Hillyer et al., 2015). There are other variables that impact the decline in performance, which is why it is still highly debated exactly how dehydration impacts cognitive function and physical performance. For example, a study that done with 40 male soccer players measured decision making efficacy during a game while being dehydrated (Fortes et al., 2018). When compared to a control group that was normally hydrated, they concluded that dehydration may be considered a mediating factor in passing decision making performance in the participants, but more research should be done to account for cofounding variables that lead to cognitive decline (Fortes et al., 2018).

The BEVQ-15 is a validated survey that assesses fluid intake over the course of a month. This 15-item questionnaire helps researchers to rapidly assess an individual's habitual fluid intake (Hedrick et al., 2012). Since its first use, the survey has been updated and tested for validity. The updated version of the questionnaire showed sufficient validity and reproducibility for total beverage consumption (Fausnacht et al., 2020). Because athletes have such unique schedules, their hydration needs are different from the normal population. Training, travel, class, and competition, all make for college athlete's hydration needs to go way up. With these demands, there needs to be an efficient and valid way to assess student athlete's fluid intake habits. The validity of the BEVQ-15 was investigated by Kostelink et al. (2021) to establish the feasibility and reliability of the questionnaire against specific gravity measures of urine along with participant rated urine color along with comparing against a 24-hour dietary recall (Kostelnik et al., 2021). Moderate associations were found between the BEVQ-15 and the dietary recalls ($P<.05$). Findings suggested that the rapid assessment questionnaire was an acceptable and valid method to determine athlete's hydration status and habits (Kostelnik et al., 2021).

It is important for athletes, especially wrestlers, to be aware of their fluid intake during the day and over time as they are constantly training, in addition to going to class during the day, which means their fluid loss is greater than non-athletes. Additionally, to perform at the highest level requires extreme discipline in all areas of their lives, including nutrition and hydration.

Whoop

Whoop is a personalized wearable technology that helps athletes and regular exercisers track and manage sleep, exercise, and physiological biomarkers such as heart rate variability (HRV), resting heart rate (RHR), and more. Whoop technology was originally released in 2015 meaning it is a relatively new tool to use to measure strain, recovery, and HRV (Comstock, 2015). Whoop uses a combination of metrics to measure recovery. These metrics are heart rate variability, resting heart rate, daily strain, respiratory rate, and sleep quality and duration (Whoop, 2023). Heart rate variability is the time difference between each heartbeat (Whoop, 2023). Daily strain is a measurement used to identify total exertion throughout each day. This is mainly based on your recovery from the day before but also includes factors such as workout intensity and duration. Whoop also measures recovery as a percentage with color indicators to let athletes know each morning if they are well recovered and ready to perform. Although research is limited on the use of Whoop by athletes, research that is available validates the use of Whoop devices to help measure sleep and recovery. Sekiguchi et al. (2019) studied the relationship between RHR, HRV, and sleep characteristics in female collegiate track and field athletes using Whoop technology. Higher resting heart rate and lower heart rate variability were both associated with an increase in time spent in deep sleep. This suggests that when there were physiological impairments, identified by Whoop, the percentage of time in deep sleep was greater to help aid recovery. This is the type of information that athletes may want to see, to help them adjust their training, recovery, and sleep to improve their performance. A validation study done in 2021 compared Whoop technology measuring HRV, with the gold standard measurement of the electrocardiogram (ECG) (Bellenger et al., 2021). After analyzing measurements from both technologies over a three-month period, there was an agreeable association between both Whoop and ECG measures of heart rate and HRV. Another study using the Whoop Technology measured variability of day-to-day HR and HRV in Olympic water polo athletes during training before the Tokyo Olympic games (Miller et al., 2021). Additionally, researchers looked at the effect training load had on day-to-day variability of HR and HRV. What was found was that Whoop derived HR and HRV was deemed valid and comparable to other recording devices used in scientific research (Miller et al., 2021). In addition to HR, HRV, and other biomarkers that Whoop can measure, Whoop calculates and estimates sleep duration and sleep quality. Users can see a detailed description of their sleep each morning with times for total sleep, wake time, light sleep, REM sleep, and slow wave sleep (SWS). Miller et al. also investigated Whoop auto and manual measured sleep (Miller et al., 2021). Additionally, the validity of the Whoop device was also compared to other commercial sleep wearable devices. Although many devices differ in specificity and sensitivity for measurements of sleep categories, Whoop appeared to be consistent across all sleep categories and did not show a huge tradeoff between sensitivities of the different categories (Miller et al., 2021). It was concluded that Whoop sleep technology, both automatic and manual methods, were validated to be used as a practical alternative to the polysomnography for sleep measurements (Miller et al., 2021).

HRV

Heart rate variability is the duration between heartbeats measured by the lengths of successive R peaks in the QRS complex of an electrocardiograph (Makivić et al., 2013). Figure 1 illustrates changes in R-R interval lengths, leading to the calculation of HRV.

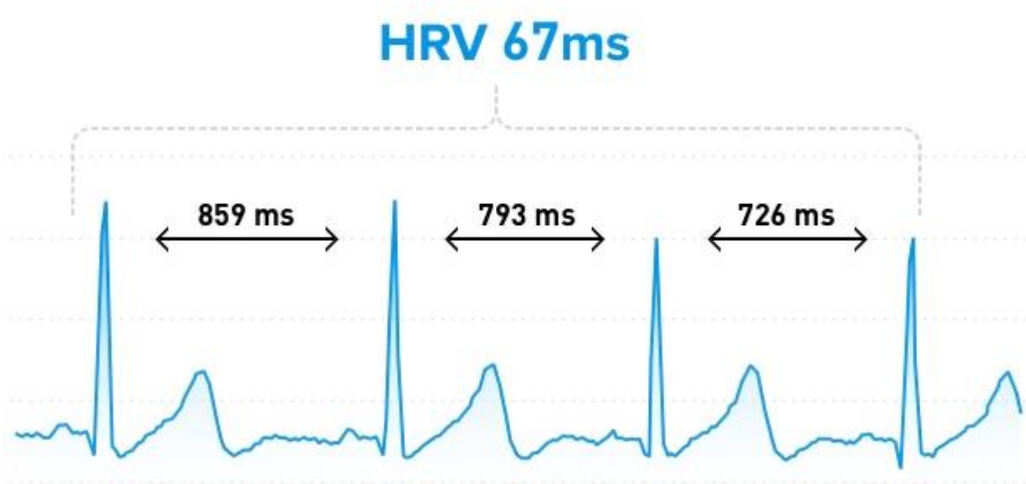

Figure 1. The peaks of the QRS-complex are the R phases. The time between each R peak is called the RR interval. Whoop measures HRV using the root mean square of successive R intervals or heartbeats (Whoop, 2021).

HRV has recently been used to help identify changes in the autonomic nervous system and physiological responses to exercise (Makivić et al., 2013). HRV can vary depending on training load, fitness level, and recovery period for a particular athlete. It can look different for every athlete but in general, a higher HRV is characterized by a dominance of the sympathetic nervous system (SNS) or the “fight or flight” part of the nervous system during exercise (Makivić et al., 2013). The balance between the parasympathetic (PNS) and sympathetic nervous systems affect heart rate and in turn is goal of improved HRV (Makivić et al., 2013). Higher HRV indicates better balance between the SNS and PNS which is advantageous to athletes to balancing training and recovery.

Athletes and regular exercisers regularly enter a stage of functional overreaching which is a period of increased training load to increase performance over time (Meeusen et al., 2013). What does not lead to increased performance is overtraining syndrome which is characterized as a prolonged maladaptation that disrupts mechanisms in the body (Meeusen et al., 2013). Overtraining over an extended period of time can lead to disrupted and decreased HRV and perhaps a decrease in athletic performance (VanDusseldorp & Kravitz, 2015). This evidence indicates that using HRV as a monitoring tool in training programs may be beneficial for athletes' performance. Research has shown that HRV is a relatively easy measurement to monitor fitness level or athletic performance (Plews et al., 2013). With a small amount of solid research out there, the results are mixed. For example, Plews et al. studied elite athletes and showed both increases and decreases in HRV to be associated with negative adaptation (Plews et al., 2013). Additionally, increased cardiovascular fitness was observed with atypical decreases in HRV (Plews et al., 2013). With this, it is apparent that more research is needed to understand the ways in which HRV can be used to monitor fitness level, training load, and athletic performance. As mentioned, HRV is normally considered a convenient tool to assess individual adaptation to training (Plews et al., 2013). Often, the body’s reaction to stress in any form can be seen by variations in HRV. For example, A study conducted on 81 healthy males investigated the associations between physical activity, cardiorespiratory fitness, body composition, and HRV (Teisala et al., 2014). Results of the study found significant associations between the different variables, and that greater cardiorespiratory fitness levels and more favorable body composition were associated with lower stress levels and increased HRV which is in line with earlier research (Teisala et al., 2014). In literature, there are atypical associations between HRV and cardiorespiratory fitness levels but most evidence points towards increased HRV being associated with positive training adaptations like increased cardiorespiratory fitness levels and increased recovery from exercise (Teisala et al., 2014). HRV assessment is also a great tool for patients in cardiac care to help measure autonomic nervous system activity (McMillan, 2002). Depending on the stimulus or stress, either the sympathetic or parasympathetic nervous system becomes activated. The level to which a person can adapt to the activation of the autonomic nervous system can be characterized by HRV (Teisala et al., 2014). Although not researched in athletes, a study conducted by Jurca et al., investigated the effect a moderate-intensity exercise routine has on HRV in sedentary postmenopausal women (Jurca et al., 2004). Results of this study found that moderate aerobic exercise increased HRV in sedentary postmenopausal women compared to control group who did not partake in exercise intervention ($P<0.001$) (Jurca et al., 2004). Although this study's population is significantly different from college athletes, results found align with adaptations that are often found in elite athlete's training.

Performance

The vertical jump test is often used by coaches to help measure readiness to perform or performance in general. It can help identify if athletes are being over-trained or gaining anaerobic power from an effective training program (Klavora, 2000). There are many ways to measure vertical jump; the most basic way being a standard metal pole with plastic vanes along the top to measure the peak vertical jump. Additionally, there are more advanced and efficient ways to measure vertical jump as with a contact mat or with force platforms that measure vertical jump electronically. For example, a study conducted to analyze two different vertical jump tests, used young male basketball players to assess validity of the force platform vertical jump assessment tool (Gillett et al., 2021). Results of the vertical jump reach test varied depending on testing conditions, but the data suggested that data from the force platforms, when performed with hands on hips, can be used to predict jump height during functional performance (Gillett et al., 2021).

There is other evidence in literature that vertical jump is an effective measure of performance or readiness to perform. For example, a study examined the relationship between athletic performance tests, such as the vertical jump test, and playing time in male, Division 1 college basketball players (Hoffman et al., 1996). Correlations were made between coaches' evaluation of each player's ability that correlated with athletic performance tests including the 1-RM squat vertical jump test, and other speed and agility tests. Although vertical jump, speed, and agility were all consistent correlators to playing time, vertical jump height was determined to be a strong predictor in each regression equation while speed and agility were only moderate predictors (Hoffman et al., 1996). These results suggest that vertical jump is a strong predictor of playing time in college basketball players and may even be a predictor of athletic performance. Another study by Ostojic et al. (2010) verified that vertical jump testing correlated with athletic performance, even more so than other anaerobic tests (Ostojić et al., 2010). Most of the literature on this topic are focused on the ability to use vertical jump tests to monitor lower body power performance and sometimes fatigue post exercise or post competition. However, a study conducted by Watkins et al., (2017) used vertical jump tests as a measure of readiness to perform and fatigue (Watkins et al., 2017). Due to physiological stress on the body from previous lower body exercise, results showed that vertical jump height decreased and remained 8% less than baseline even 2 days after and at the start of a second workout (Watkins et al., 2017). Although more research on this topic would be beneficial, practical application of these findings could use pre-vertical jump height as a tool to gauge readiness for a strenuous resistance training workout, or perhaps other exercises too (Watkins et al., 2017). To better understand athletes' response to training and readiness to perform, tools such as the vertical jump assessment might be practical for athletes to use before training or competition. Vertical jump performance is usually evaluated in specific conditions to measure and predict objective performance outcomes. Some studies in literature aim to assess the validity of other vertical jump assessment tools that are more convenient but may be less sensitive and less precise in their measurements. One study assessing the validity of two other vertical jump assessment tools, compared jumps heights of rugby players using Optojump and Myotest systems and compared them to the gold standard force platform (Castagna et al., 2013). Results shows that alternative vertical jump assessment tools were valid when a force platform is not available but even more so, the study further verified the use of force platforms as the gold standard to measure vertical jump height (Castagna et al., 2013). This is why the vertical jump test is an effective way of helping coaches know what their athletes' needs are during a training program and a great way of measuring readiness to perform.

When predicting or measuring readiness to perform there are multiple variables to consider. Training load, recovery, psychological stress are variables that impact an athlete's performance or readiness. Whoop technology combines data from all these variables into something called daily strain. Whoop uses information from heart rate, workout duration, psychological stress, and more, to measure strain daily. Strain is scored on a scale of 0 to 21.

Higher scores indicate more strenuous activities and stress during the day (Rowan et al., 2022). In a study that looked at heart health in active, pregnant women, HRV, RHR, and measures of strain were measured over a 5 month period (Rowan et al., 2022). As expected, activity levels decreased over the course of pregnancy which reduced daily strain, but there were also decreases in HRV and increases in RHR that indicated correlations with daily strain (Rowan et al., 2022). Strain measured by Whoop is a good indicator of cardiovascular health and often predicts recovery the next day as well. Whoop technology is interesting in that it informs the user if they are at optimal strain or “overreaching” for the day. Overreaching can be beneficial on occasion for further fitness gains and increased performance but overtime, consistent overreaching can lead to decline in recovery and performance.

POMS Survey

The profile of mood states (POMS) survey is a validated questionnaire that identifies athlete’s distinct mood states over time. The questionnaire consists of adjectives that participants mark to indicate their current mood state (Dingley, 2020). Grove and Prapavessis (1992) validated the use of an abbreviated POMS questionnaire tailored to competitive athletes that removed several adjectives and substituted other adjectives that assessed self-esteem (Grove & Prapavessis, 1992). Although it was widely known that depression and altered mood states negatively impact athletic performance, the POMS survey has been shown to predict athletic performance among a wide variety of athletes and sports (Lochbaum et al., 2021). Additionally, Lochbaum et al. (2021) found that the POMS survey more accurately explained successful athletic performance in shorter duration sports compared to longer duration. That is why this questionnaire is a valid survey to help predict athletic performance in wrestlers. Wrestling is a short duration sport compared to soccer or lacrosse. Further, even though wrestling can be a team sport it is more of an individual sport and the POMS survey was found to be more accurate in explaining athletic performance in individual sports compared to team sports (Lochbaum et al., 2021).

Other uses of the POMS questionnaire in literature are assessments of elite athletes' mood states, specifically anxiety and depressive symptoms (Petito et al., 2016). Petito et al., studied 133 elite athletes looking at the relationship between personality and the occurrence of anxiety and depressive symptoms. After assessing mood states using the POMS questionnaire and the occurrence of psychiatric personality disorders during clinical interviews, significant correlations between neuroticism and symptoms of anxiety and depression were examined. Looking back, it was suggested that neuroticism and sport related stress can predict adverse mental health outcomes in athletes and can be identified by the POMS questionnaire (Petito et al., 2016).

There is consensus among researchers that the relationship between overall load, athlete health, and performance can be viewed as a continuum (Nässi et al., 2017). Meaning that every athlete lies somewhere along this continuum depending on the variables mentioned. A review of the scope of current psychological tools used in training looked at different assessments such as POMS questionnaire, the emotional recovery questionnaire, total quality recovery scale, and more, for their reliability (Nässi et al., 2017). The review suggests that there is an array of valid and reliable instruments that can be used to assess mood states in athletes and the POMS survey is one of them. With this in mind, it is important to know that while these tools can be of good use, practical suitability changes depending on context (Nässi et al., 2017). That is why results may vary depending on sport, gender, age, training load, and more. Another review of athletes, sports, and the POMS survey, acknowledged that improvements in methodologies used to study relationships between sport, exercise, and mood need to be made. Further validation of the abbreviated form of the survey needs to be done and increased use of the POMS for mood profiling in athletes needs to be conducted (Leunes & Burger, 2000).

Sleep in College Students

It is widely known that college students do not have the best sleep schedules. Not to mention college athletes who have an even busier schedule than just regular students. There is a high demand for their time balancing classes, practice, and social life that often leads to inadequate sleep. Even though not all the processes of sleep are known, there is increasing evidence that suggests sleep is one the key aspects of recovery and reduction of fatigue in athletes (Doherty et al., 2021). Doherty et al. found that elite athletes tend to overestimate their sleep time, they often sleep less than recommended, and their sleep quality it poor; even though the demands for sleep and recovery are higher (Doherty et al., 2021). Results from this study show that adequate coach and athlete education on sleep and recovery needs to be further developed and implemented with teams and organizations (Doherty et al., 2021). It was also noted that the importance of monitoring sleep and recovery processes to identify changes or issues during training (Doherty et al., 2021).

Although athletic performance and what is defined as "adequate sleep" may vary in literature, there are several studies that have investigated the correlation between sleep in college students and athletic performance. Previous data suggest that athletes have an increased need for sleep ranging anywhere from 7-9 hours (Bird, 2013). Because many student athletes do not meet their sleep needs, they could see a decrease in athletic performance. A systematic review was conducted to evaluate sleep intervention studies that helped improve performance and recovery in competitive athletes (Bonnar et al., 2018). Bonnar (2018) reviewed studies that had several sleep interventions like napping, post workout recovery techniques, better sleep hygiene, and increasing sleep duration. From these studies, sleep extension had the highest effect on performance. Another study done by Reilly and Piercy (1994) investigated performance in collegiate weightlifters after 4 days of sleep deprivation (Reilly & Piercy, 1994). Results showed that participants lifted less overall weight on a maximum deadlift and maximum leg press after 4 days of sleep deprivation compared to a 4-day control period where participants had normal sleep. These findings further support the idea that sleep plays an important role in athletic performance and that the need to monitor sleep is crucial to create a healthy sleep schedule. Based on previous literature, there is plenty of room for sleep optimization in athletes. One of the biggest issues is the lack of understanding athletes have on the importance sleep has on their recovery and performance. The other issue is that athletes do not know how to improve their sleep hygiene (Lastella et al., 2015). A study that investigated elite youth athletes found associations between sleep hygiene habits and sleep quality (Knufinke et al., 2018). Common sleep hygiene behaviors that had caused delayed sleep onset and other negative sleep consequences were blue-light exposure, frequent late-evening consumption of heavy meals, and caffeine (Knufinke et al., 2018). Since there is a strong association between sleep hygiene and sleep quality, athletes need a better understanding of healthy sleep hygiene behaviors and how it can improve their performance. Training schedules seem to be a significant factor of sleep quality in both team sport athletes and individual sport athletes (Driller et al., 2022). Better sleep characteristics were observed in elite individual sport athletes compared to team sport athletes (Driller et al., 2022). The authors attribute this to team sports having early morning and late evening high-intensity training (Driller et al., 2022).

Summary

The purpose of this study was to investigate performance and readiness indicators of Division 1 NCAA collegiate wrestlers during an in-season training period. The main objectives of this study are to assess the feasibility of Whoop technology in Division 1 wrestlers to help manage training load during season, determine whether strain and recovery as measured by Whoop are correlated with performance, self-perceived fatigue, and hydration status, and lastly to determine if HRV is correlated with sleep, hydration, performance, and other Whoop measures such as recovery, HRV, RHR, hours of sleep, sleep need, daily strain, and % of strain accounted for from workouts.

From existing literature there is not a lot of research using Whoop to assess biofeedback measures in athletes. This alone is relatively new in research and understanding the use and feasibility of wearable technology such as Whoop could be beneficial for science and athletes both. Additionally, although there is relatively sufficient research regarding vertical jump tests, and hydration for athletes, there are gaps in literature where hydration and physiological readiness indicators are used to predict performance. The POMS questionnaire is used in literature to assess mood disturbances of athletes cause by training, stress, and competition and often to predict athletic performance. Similar to previous uses in research, the POMS questionnaire will be used in this study to assess mood disturbance and self-perceived fatigue in association with indicators from Whoop, hydration status from BEVQ-15 survey, and vertical jump which is an indicator of readiness to perform. The combination of these assessments on an athletic population is unique to literature and could benefit the advancement of athletic training and performance, specifically in Division 1 collegiate wrestlers.

The main purpose of this study is to measure performance and readiness indicators of Division 1 NCAA collegiate wrestlers during a 6-week period in season while training and competing. The specific aims of the study are: 1. Assess the feasibility of using Whoop technology in NCAA D1 Wrestlers to assess Whoop collected data changes over the course of the season, 2. Validate the use of Whoop technology in NCAA D1 Wrestlers to determine whether strain, recovery, and HRV as measured by the Whoop are correlated with performance, self-perceived fatigue, and readiness, and 3. Determine if Heart Rate Variability correlates with sleep quality, quantity and monthly hydration status as measured by the BEVQ-15.

METHODS AND MATERIALS

Participants and Recruitment

Student athletes on the Virginia Tech Wrestling Team were recruited to voluntarily participate in the 6-week pilot study during the spring 2023 semester. A recruitment speech was given to all 29 wrestlers on the Virginia Tech roster before practice. A sign-up sheet was available for any wrestler to sign up if they were interested. Once participants volunteered to participate, consent forms were signed by each volunteer, and each wrestler was assigned a participant ID for anonymity during data collection. Although 29 wrestlers were recruited, 10 wrestlers volunteered to participate in the study. After data collection was completed, 9 participants had sufficient data for analysis while one participant was omitted due to large pieces of missing data. Demographic data can be seen in Table 1. Before data collection started, the study was approved by the Virginia Tech Institutional Review Board (IRB) to study human subjects. Additionally, the study was approved by the Virginia Tech Athletics Department to conduct research on NCAA D1 athletes that attend Virginia Tech.

Age (years)	Average: 21.2						
Weight Class	125 1 (11.1%)	157 1 (11.1%)	165 1 (11.1%)	174 3 (33.3%)	184 1 (11.1%)	197 1 (11.1%)	285 1 (11.1%)
Academic Standing	Freshman 0 (0%)	Sophomore 3 (33.3%)	Junior 3 (33.3%)	Senior 1 (11.1%)	5th Year 2 (22.2%)		
Ethnicity	White 8 (88.8%)	Black 1 (11.1%)	American Indian 0 (0%)	Asian 0 (0%)	Native Hawaiian 0 (0%)	Multiple Races 0 (0%)	
First Generation Student Status	Yes 1 (11.1%)	No 8 (88.8%)					
Transfer Student Status	Yes 0 (0%)	No 9 (100%)					

Table 1. Demographic information of the 9 participants.

Wearable Technology Used

Upon consenting to participate in the study, wrestlers were provided a Whoop band (see Figure 2A) (Whoop Inc., Boston, MA) and downloaded the Whoop app on their phone using their participant ID. The Whoop band was asked to be worn at all times except during competition.

Vlad Performance ForceDecks (see Figure 2B) (VLAD Performance, Brisbaine, Queensland) were used in the Virginia Tech Olympic Weightlifting room to measure vertical jump height each week during the 4-week data collection phase.

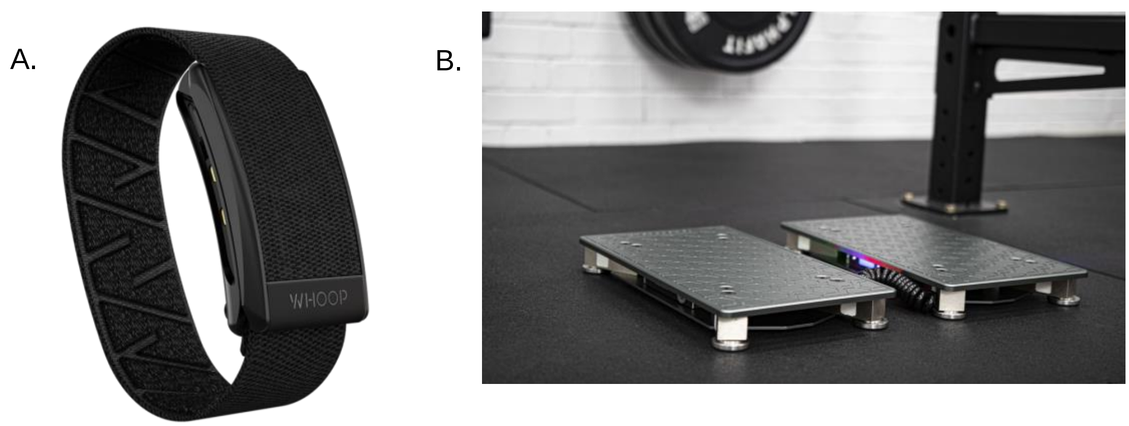

Figure 2. A. Whoop Strap. B. Vlad Performance ForceDecks.

Data Collection

Each athlete who volunteered to participate wore a Whoop band for 6 weeks in season throughout the day, while they sleep, and during training. The first two weeks were deemed an acclimatization phase to allow the Whoop to gather information on each participant before data collection began. Following the acclimatization phase, a 4-week data collection phase was used to measure the following from the Whoop bands: daily strain, daily recovery (%), heart rate variability (HRV), resting heart rate (RHR), duration of sleep, and more.

Once a week for 4 weeks during the data collection phase, wrestlers did a vertical jump test during weight training and were asked to fill out the Abbreviated POMS-40 survey to help assess self-perceived fatigue and readiness to perform (Grove & Prapavessis, 1992). For each of the adjectives listed on the survey participants answered on a scale of 0-4: “not at all,” “a little,” “moderately,” “quite a lot,” and “extremely,” respectively. Total mood disturbance was calculated by first summing the scores from the anger, fatigue, tension, confusion, and depression subscales. Then subtracting the sum of the subscales esteem and vigor from the other five and finally adding a constant of 100 to get rid of negative scores After the 4-week data collection phase, each wrestler completed a BEVQ-15 survey that asks them about their fluid intake over the past 30 days (Hedrick et al., 2012). Additionally, each wrestler completed a demographic survey to identify which weight class they wrestle at, along with other general demographic information such as race, gender, grade level, age, and if they identify as a first-generation student. One participant was omitted from the study due to inactivity and non-compliance with wearing the Whoop. Three participants did not complete the vertical jump test each week due to injury related reasons. All nine participants completed the BEVQ-15 survey at the end of the data collection phase. All but one participant completed the POMS questionnaire during the 3-week collection phase. Specific data from the Whoop that was collected daily were Recovery, HRV, RHR, hours of sleep, sleep need, and daily strain.

Data Analysis

Data from the POMS surveys were entered into an excel spreadsheet and scored based on established scoring criteria (Grove and Prapavessis, 1992). Adjectives from the POMS survey were grouped into categories which were: fatigue, anger, vigor, tension, esteem, confusion, and depression and total mood disturbance was calculated from these categories as well (Grove and

Prapavessis, 1992). Data collected via Whoop and used in analysis were percent recovery, HRV, RHR, sleep duration, sleep need, daily strain, and percent daily strain from exercise. BEVQ-15 surveys were scored based on established scoring criteria and saved to be compared to other research data (Fausnacht et al., 2020). 5 statistics software (GraphPad Software, 2023) was used to perform simple linear regression to make correlations between Whoop data, vertical jump scores, POMS scores, and BEVQ-15 daily total fl. oz. consumed.

RESULTS

Of the 6-week pilot study, there were only 3 weeks of recorded data that were analyzed. The first two weeks were deemed an acclimation period to allow the Whoop to collect data more accurately on each participant. There were delays in week 3 getting all the participants their Whoop and getting the technology set up which led to viable data recorded between weeks 4-6. During the 3 weeks, participants wore their Whoop all the time except for competition on the weekends.

Since the main purpose of this study was to investigate the overall feasibility and applicability of the Whoop technology for college wrestlers, it is important to note the usefulness that participants found in the Whoop technology. First, the study concluded with viable data from 9 out of 10 participants. A 90% compliance rate is impressive and indicates that the Whoop strap was feasible and applicable for the participants to wear and regularly see feedback from training and recovery. Additionally, a benefit of this study was that participants were given a 6-month Whoop subscription after the conclusion of the study. Since the conclusion of the study, multiple wrestlers still wear and use the Whoop strap to manage their training and sleep. Participants genuinely liked the technology and the feedback they got from their training and recovery. This further points to the feasibility and applicability of Whoop technology.

Table 2 shows all Whoop collected data that was used to calculate the mean and standard deviation for each participant, for each variable studied, for 3 weeks. Weekly, 3-week, and total participant averages were calculated.

	Participant ID	Recovery (%)	HRV	RHR	Hours of sleep	Sleep Need	Change in sleep	Daily Strain	% of strain accounted for from workouts
Week 1	300	67.29 (21.03)	132.57 (7.91)	40.00 (1.63)	6.42 (1.08)	9.75 (0.62)	-3.33 (1.38)	18.34 (1.62)	66.18 (12.97)
Week 2	300	65.71 (10.64)	131.14 (6.84)	40.86 (1.35)	6.58 (0.74)	9.63 (0.51)	-3.05 (1.05)	17.21 (2.53)	49.73 (17.48)
Week 3	300	54.43 (22.29)	107.71 (33.68)	61.00 (5.57)	6.95 (1.14)	8.92 (0.77)	-2.67 (0.62)	17.21 (3.23)	81.56 (6.54)
3-Week mean	300	67.57 (20.51)	131.33 (28.87)	40.57 (8.75)	6.58 (1.61)	9.59 (2.12)	-3.02 (1.04)	17.59 (4.46)	59.45 (20.28)
Week 1	301	59.86 (24.42)	47.43 (14.84)	64.00 (2.71)	6.64 (0.78)	8.75 (2.13)	-2.11 (2.54)	13.81 (4.30)	71.92 (15.85)
Week 2	301	45.00 (17.60)	37.71 (8.60)	66.57 (2.37)	7.38 (1.87)	9.28 (0.76)	-1.90 (1.77)	14.03 (4.07)	65.43 (13.45)
Week 3	301	60.29 (21.65)	41.57 (12.04)	67.14 (2.34)	7.77 (1.21)	8.35 (0.90)	-0.58 (1.77)	13.56 (4.34)	74.02 (8.23)
3-Week mean	301	55.05 (21.57)	42.24 (12.19)	65.90 (2.74)	7.26 (1.38)	8.79 (1.39)	-1.21 (2.07)	13.80 (4.02)	70.46 (12.70)
Week 1	302	71.43 (21.45)	125.86 (28.12)	57.43 (3.87)	7.81 (1.01)	9.05 (0.63)	-1.24 (1.12)	14.01 (4.68)	65.72 (13.81)
Week 2	302	62.43 (25.96)	116.14 (37.28)	60.29 (5.82)	7.21 (1.53)	8.44 (1.76)	-1.23 (2.47)	14.34 (3.88)	54.13 (20.03)
Week 3	302	54.43 (22.29)	107.71 (33.68)	61.00 (5.57)	6.95 (1.14)	8.92 (0.77)	-1.98 (1.42)	15.20 (4.59)	81.56 (6.54)
3-Week mean	302	62.76 (23.24)	116.57 (32.44)	59.57 (5.14)	7.32 (1.24)	8.81 (1.14)	-1.20 (1.72)	14.52 (4.20)	66.29 (18.00)
Week 1	303	58.71 (26.85)	99.29 (33.22)	55.43 (7.48)	7.91 (1.04)	6.81 (1.04)	1.10 (0.36)	12.84 (5.77)	65.55 (31.46)
Week 2	303	52.50 (21.22)	100.83 (15.54)	53.67 (2.34)	6.50 (1.65)	7.54 (2.02)	-1.05 (2.44)	12.89 (4.37)	61.73 (31.25)

Week 3	303	50.43 (15.54)	103.00 (12.96)	53.57 (3.05)	5.79 (1.47)	9.31 (1.65)	-1.05 (2.54)	13.70 (5.54)	71.70 (13.07)
3-Week mean	303	53.95 (20.88)	101.05 (21.62)	54.25 (4.78)	6.74 (1.61)	7.90 (1.87)	-1.16 (2.75)	13.14 (5.01)	66.07 (25.08)
Week 1	304	64.71 (10.86)	62.29 (3.35)	49.57 (1.40)	6.99 (1.32)	9.09 (0.52)	-2.10 (1.48)	14.36 (4.48)	77.28 (15.09)
Week 2	304	63.50 (22.37)	58.25 (6.55)	52.25 (2.22)	7.53 (1.51)	9.49 (0.43)	-1.97 (1.49)	15.08 (3.59)	82.48 (7.25)
Week 3	304	75.14 (13.93)	59.43 (7.46)	52.29 (1.11)	7.24 (1.06)	9.28 (0.69)	-2.04 (1.07)	16.24 (3.07)	73.60 (11.11)
3-Week avg	304	68.50 (15.11)	60.28 (5.84)	51.22 (1.96)	7.21 (1.21)	9.25 (0.57)	-2.05 (1.25)	15.24 (3.66)	77.20 (11.84)
Week 1	305	58.43 (21.71)	108.86 (33.61)	54.57 (6.60)	7.10 (1.49)	8.95 (0.89)	-1.85 (1.28)	14.23 (4.12)	71.32 (19.25)
Week 2	305	45.00 (22.31)	92.33 (25.03)	55.67 (7.20)	7.32 (2.23)	8.29 (0.54)	-0.96 (2.62)	14.17 (3.36)	69.80 (19.02)
Week 3	305	64.00 (13.81)	111.71 (12.92)	53.00 (1.91)	6.50 (1.01)	7.49 (1.25)	-0.99 (1.52)	15.17 (4.54)	76.32 (8.95)
3-Week avg	305	56.35 (20.10)	104.90 (25.44)	54.35 (5.46)	6.96 (1.57)	8.24 (1.10)	-1.28 (1.80)	14.54 (3.88)	72.58 (15.51)
Week 1	306	65.57 (18.43)	88.14 (4.18)	43.29 (1.80)	6.99 (1.54)	9.65 (0.76)	-2.66 (1.77)	15.60 (2.01)	71.03 (16.72)
Week 2	306	67.29 (17.45)	88.86 (12.47)	44.14 (2.79)	6.77 (1.39)	8.92 (1.02)	-2.15 (1.45)	15.50 (3.87)	78.68 (10.54)
Week 3	306	70.57 (11.87)	91.86 (5.96)	45.29 (1.80)	6.94 (1.42)	9.63 (0.84)	-2.69 (1.30)	15.81 (4.93)	67.18 (8.04)
3-Week avg	306	67.81 (15.49)	89.62 (8.08)	44.24 (2.23)	6.90 (1.38)	9.40 (0.90)	-2.50 (1.46)	15.64 (3.61)	72.30 (12.57)
Week 1	307	61.80 (23.42)	139.40 (25.69)	50.20 (3.77)	6.27 (1.59)	10.18 (0.40)	-3.90 (1.34)	15.53 (2.19)	78.64 (6.98)
Week 2	307	50.00 (21.21)	112.50 (20.51)	50.50 (3.54)	5.23 (0.08)	9.17 (1.57)	-3.95 (1.49)	13.10 (7.66)	86.85 (0.07)
Week 3	307	69.00 (12.52)	133.14 (12.05)	51.29 (2.69)	6.39 (1.10)	9.00 (1.42)	-2.61 (1.53)	14.00 (5.15)	73.72 (26.68)
3-Week avg	307	63.71 (17.92)	132.43 (19.56)	50.79 (2.99)	6.18 (1.23)	9.45 (1.22)	-3.26 (1.50)	14.41 (4.58)	77.96 (17.30)
Week 1	309	80.60 (15.71)	151.80 (15.56)	45.00 (4.69)	6.78 (1.54)	8.35 (1.86)	-1.57 (3.19)	13.44 (4.11)	60.82 (4.27)

Week 2	309	61.50 (19.07)	139.83 (23.79)	49.50 (7.23)	6.28 (0.98)	9.35 (0.85)	-3.07 (1.09)	15.47 (2.66)	55.33 (14.48)
Week 3	309	68.00 (12.73)	148.50 (0.71)	48.00 (0.00)	6.57 (2.12)	8.85 (0.61)	-2.28 (2.73)	11.40	N/A
3-Week mean	309	69.85 (18.19)	145.77 (18.72)	47.54 (5.81)	6.52 (1.27)	8.89 (1.13)	-2.37 (2.24)	14.16 (3.49)	58.38 (9.81)
Total Participant mean		62.46 (19.40)	100.17 (36.75)	52.30 (8.51)	6.89 (1.34)	8.91 (1.27)	-2.02 (1.92)	14.81 (4.05)	69.15 (16.74)

Table 2. Whoop collected mean and standard deviation for 9 individual participants and for the full population for each variable measured for 3 weeks. N/A = not applicable (not enough data).

In addition to Whoop collected data, Table 3 shows all BEVQ-15 survey data collected at the end of the data collection phase.

Participant ID	Water: Avg daily fl. Oz.	Sugar Sweetened bev: Avg Daily fl. Oz.	Sugar Sweetened bev: Avg daily kcals	Total bev: Avg daily fl. Oz.	Total bev: Avg daily kcals
300	96	0	0	199.86	414.49
301	48	1.71	23.77	49.72	23.77
302	36	32	448	82.29	641.26
303	96	0	0	110	166.21
304	48	7.14	49	78	418.62
305	120	8	66.5	141.14	84.16
306	60	20	282.57	80	282.57
307	48	9.71	64.51	75.14	375.52
309	48	0	0	76.29	95.33
Total Participant Mean	66.67	8.73	103.82	99.16	277.99

Table 3. BEVQ-15 survey collected data summary from the 9 individual participants and full population.

Although no significant data was found from the POMS questionnaire, data from the 9 participants for 3 weeks is summarized in Table 4.

	Participant ID	Vigor	Esteem	Fatigue	Tension	Anger	Confusion	Depression	Total Mood Disturbance
3-Week avg	300	21.33 (3.79)	5.67 (4.04)	0.33 (0.58)	1.67 (1.53)	2.67 (3.79)	4.33 (1.53)	0.67 (1.15)	82.67 (13.43)
3-Week avg	301	14.00 (2.65)	7.67 (0.58)	1.00 (1.00)	3.00 (2.65)	1.00 (1.73)	0.33 (0.58)	0.00 (0.00)	83.67 (4.04)
3-Week avg	302	5.00 (1.00)	3.67 (1.53)	7.67 (1.53)	4.33 (0.58)	1.00 (1.00)	4.67 (0.58)	1.00 (1.00)	110.00 (6.08)
3-Week avg	303	19.33 (3.79)	11.33 (1.15)	1.67 (2.08)	1.67 (1.15)	0.00 (0.00)	1.00 (1.00)	0.00 (0.00)	73.67 (9.07)
3-Week avg	304	5 (N/A)	2 (N/A)	1 (N/A)	0 (N/A)	0 (N/A)	0 (N/A)	0 (N/A)	94 (N/A)
3-Week avg	305	8.50 (6.36)	0.00 (0.00)	2.00 (2.83)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	93.50 (3.54)
3-Week avg	306	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)
3-Week avg	307	16.67 (3.21)	9.00 (1.00)	2.00 (0.00)	1.33 (1.53)	0.00 (0.00)	0.33 (0.58)	0.00 (0.00)	78.00 (3.46)
3-Week avg	309	11.00 (2.00)	2.67 (0.58)	2.00 (0.00)	2.33 (0.58)	0.00 (0.00)	0.67 (0.58)	0.00 (0.00)	91.33 (2.52)
Total Participant mean		12.60	5.25	2.21	1.79	0.58	1.42	0.21	88.35

Table 4. POMS questionnaire mean and standard deviation for 9 individual participants for 3 weeks and from full population. *N/A = not applicable – didn't complete the survey or only completed one week.

Lastly, we used the vertical jump test to measure performance and predict readiness.

Table 5 shows vertical jump data over the 3-week data collection phase for each participant.

Participant ID	Vertical Jump (inches)
300	13.43 (0.67)
301	13.77 (0.95)
302	15.17 (0.59)
303	17.33 (0.31)
304	17.7*
305	N/A
306	N/A
307	14.87 (1.22)
309	N/A

Table 5. Vertical jump collected data from 9 participants from 3-weeks of data collection. N/A = not applicable – 3 participants didn't do the vertical jump test because of injuries. *Only completed one week of vertical jump tests.

Data from the Whoop recorded each participant's predicted recovery and their HRV. Simple linear regression for daily recovery and HRV are shown in Figure 3. There was a significant, positive correlation between recovery percentage and HRV (P<0.0001). Whoop technology is programed to calculate recovery using HRV as a metric which likely has implications to the strong association between the two.

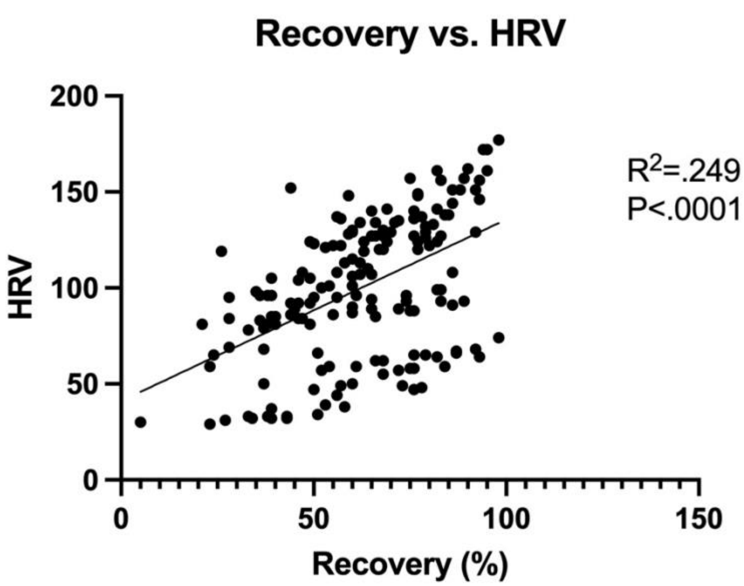

Figure 3. 9 participants daily recorded recovery and HRV data from Whoop for 3 weeks generating 27 data points for each participant.

Recovery also was also associated with RHR as Whoop also uses RHR as a metric to calculate recovery. Figure 4 shows the recovery percentage of each participant for 3 weeks with RHR for each participant as well. As displayed in the graph, there was a significant negative correlation between recovery and RHR (P<0.0001).

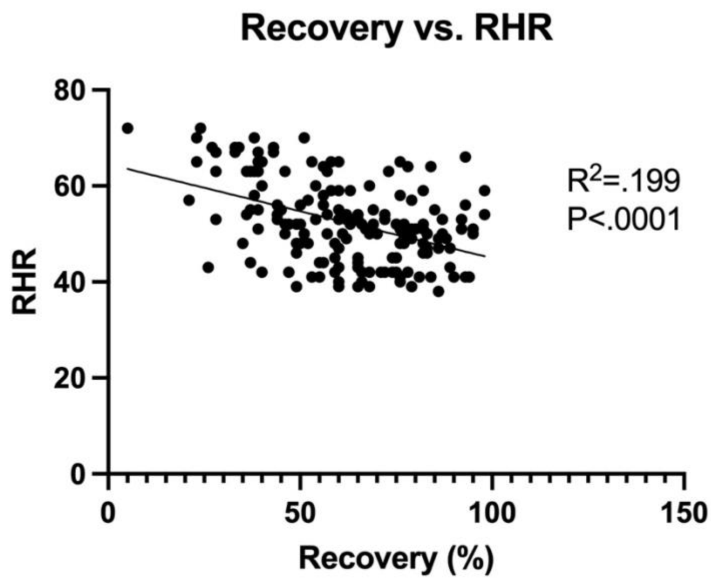

Figure 4. 9 participants daily recorded Recovery and RHR data from Whoop for 3 weeks generating 27 data points for each participant.

Another measurement that was associated with recovery was sleep. Simple linear regression for recovery percentage and hours of sleep is shown in figure 5. Sleep was significantly, positively correlated with recovery (P=0.0001).

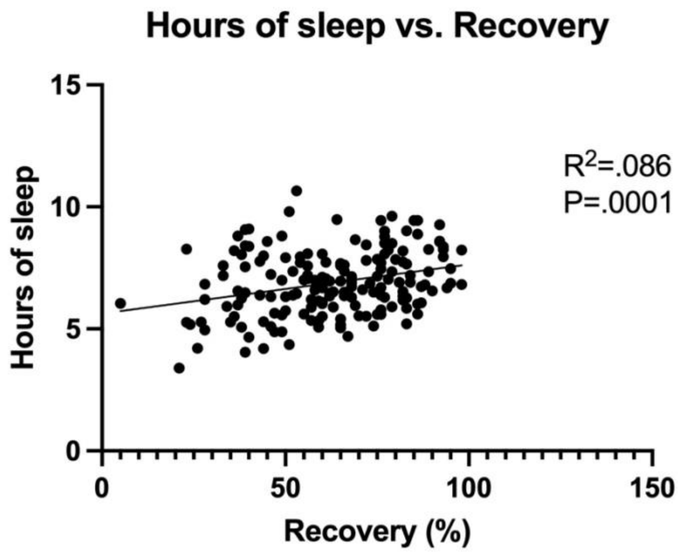

Figure 5. 9 participants daily recorded sleep (hours) and recovery data from Whoop for 3 weeks generating 27 data points for each participant.

Additionally, change in sleep duration was calculated by subtracting hours slept from hours needed as determined by Whoop. As displayed by Figure 6. Change in sleep duration is significantly, positively correlated with recovery (P=0.003).

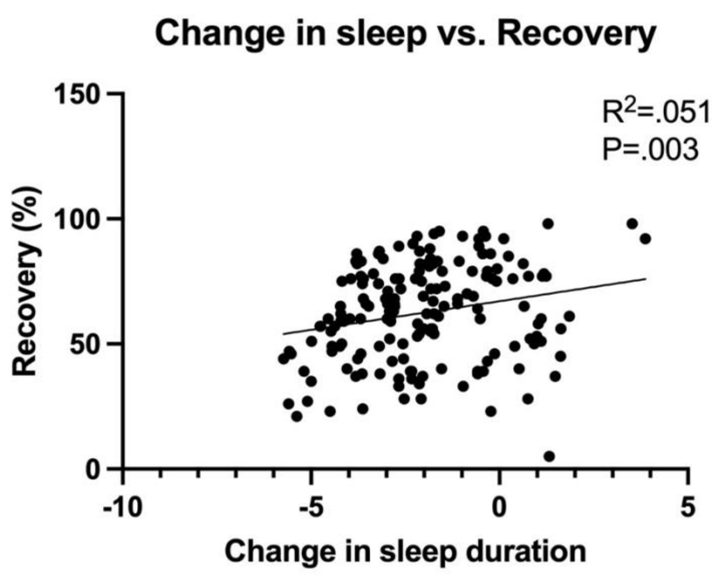

Figure 6. 9 participants daily recorded recovery and calculated change in sleep (hours slept – hours needed) data from Whoop for 3 weeks generating 27 data points for each participant.

As collected by daily Whoop measurements, there was an association between HRV and RHR. As shown in Figure 7. There is a strong, negative, correlation between HRV and RHR (P<0.0001)

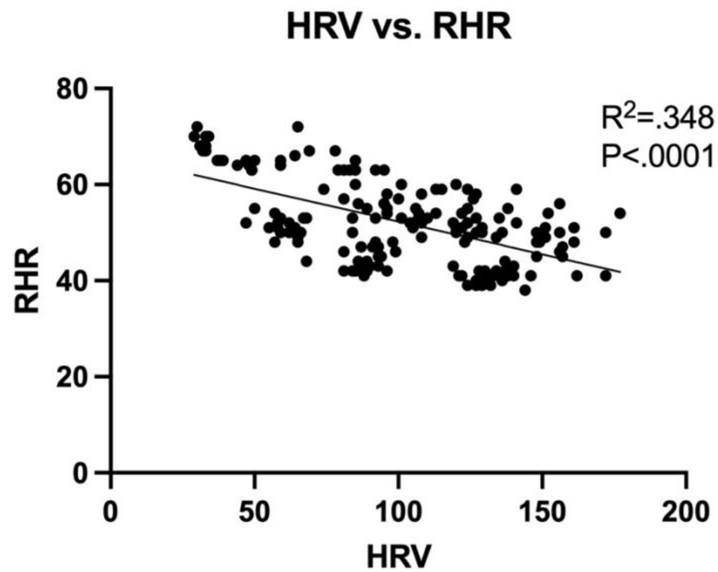

Figure 7. 9 participants daily recorded HRV and RHR data from Whoop for 3 weeks generating 27 data points for each participant.

The next significant measurement collected from Whoop was strain. Strain was significantly, negatively correlated with hours of sleep (P=0.021), Figure 8. As expected, Strain was also significantly, negatively correlated with participant's change in sleep as shown in Figure 9 (P=0.0095).

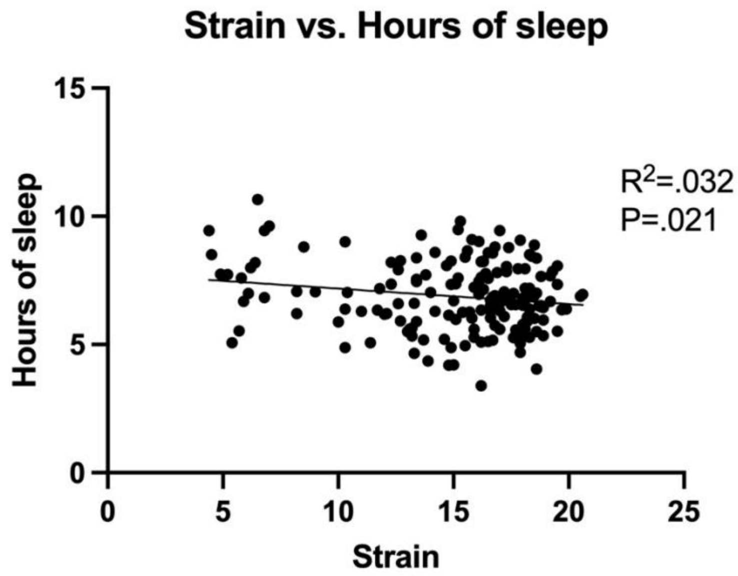

Figure 8. 9 participants daily recorded strain and sleep data from whoop for 3 weeks generating 27 data points for each participant.

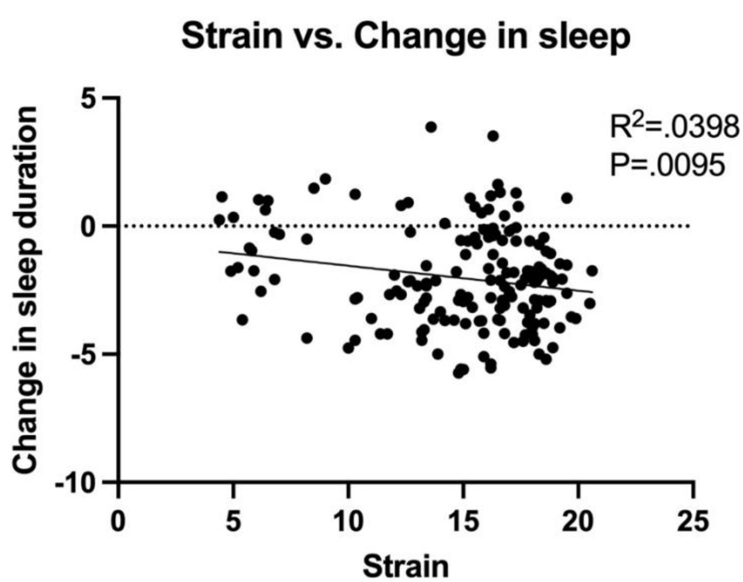

Figure 9. 9 participants daily recorded strain and calculated change in sleep (hours slept – hours needed) data from Whoop for 3 weeks generating 27 data points for each participant.

In addition to sleep, strain was a factor that influenced RHR. As shown in Figure 10 strain was significantly, negatively correlated with RHR (P=0.0002)

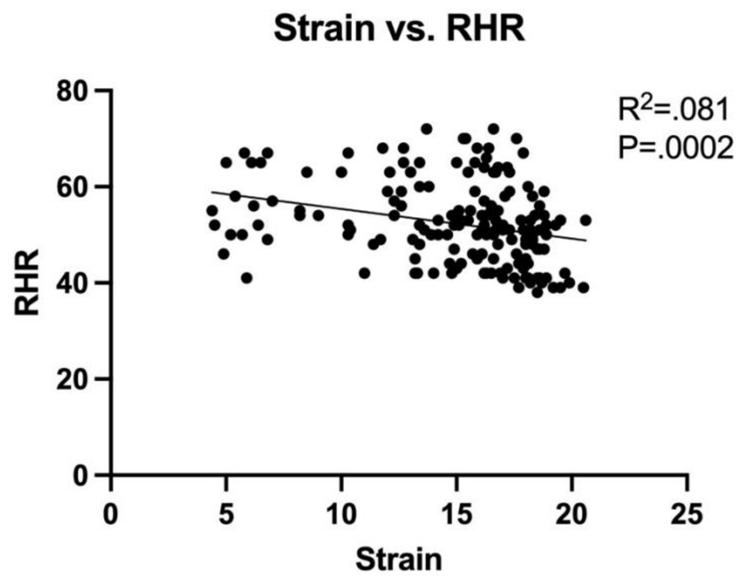

Figure 10. 9 participants daily recorded strain and RHR data from Whoop for 3 weeks generating 27 data points for each participant.

When comparing Whoop data to other data measured in the study, associations varied. One interesting finding was the correlation between daily strain and performance or readiness to perform measured via vertical jump test. As shown in Figure 11. Weekly averages of daily strain were significantly, negatively correlated with weekly vertical jump averages (P=0.037).

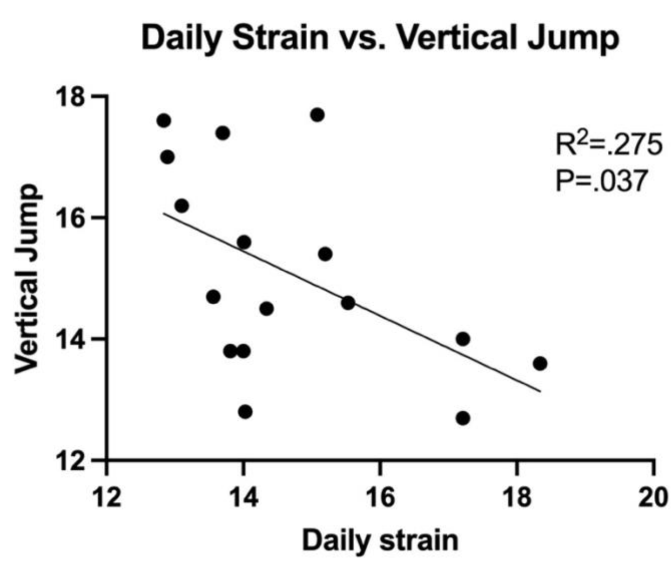

Figure 11. 9 participants weekly averaged daily strain and weekly averaged vertical jump scores for 3 weeks generated 9 data points for each participant.

Findings of the study also found associations between sleep, sleep deficit, and RHR. As displayed in Figure 12 and Figure 13, there was a significant, positive correlation between sleep and RHR (P=0.041), and a significant, positive correlation between change in sleep and RHR (P=0.0007).

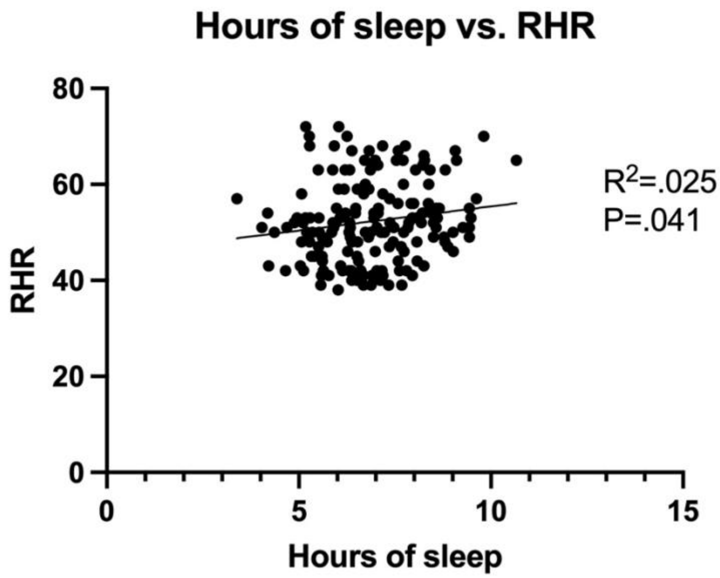

Figure 12. 9 participants daily recorded sleep and RHR data from Whoop for 3 weeks generating 27 data points for each participant.

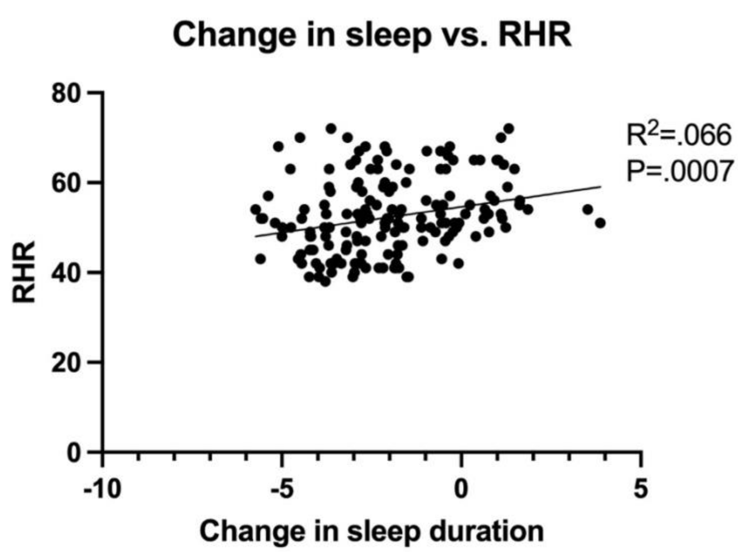

Figure 13. 9 participants calculated change in sleep (hours slept – hours needed) and recorded RHR from Whoop for 3 weeks generating 27 data points for each participant.

Other measures of Whoop were used in the analysis to investigate correlations such as strain vs. HRV and strain vs. recovery, but no significant correlations were found. Statistical analyses were also done on other measures in the study such as daily fluid intake and recovery, HRV, RHR, hours of sleep, change in sleep, daily strain, and vertical jump. Although daily fluid intake varied among participants over 3 weeks, no significant correlations were found between these measures.

Additionally, analysis was done on self-reported results from the POMS questionnaire including the seven categories of adjectives: Fatigue, vigor, esteem, tension, anger, confusion, depression, and total mood disturbance (Grove and Prapavessis, 1992). These eight variables were compared with whoop measures of recovery and HRV and total mood disturbance was compared with vertical jump, but no significant correlations were found.

Performance, as measured using vertical jump, was analyzed with HRV, recovery, RHR, hours of sleep, change in sleep, and daily fluid intake but no significant correlations were found here either.

DISSCUSSION

The main purpose of this study was to measure performance and readiness indicators of Division 1 NCAA collegiate wrestlers during a 6-week period in-season while training and competing. The specific aims of the study were to: 1. Assess the feasibility of using Whoop technology to collect data changes over the course of the season, 2. Determine whether strain and recovery as measured by Whoop, are correlated with performance, self-perceived fatigue, and hydration status, and 3. Determine if Heart Rate Variability is correlated with sleep, hydration, performance, and other Whoop measurements.

From this study, Whoop technology wearable devices were generally found to be feasible to assess changes in performance and readiness indicators over the course of 3 weeks during in-season. There were significant correlations between strain and performance from data collected by the Whoop and vertical jump tests. Specifically, vertical jump height was negatively associated with daily strain. Further, HRV was found to be significantly correlated with recovery and RHR. RHR was negatively associated with HRV and HRV was positively associated with daily recovery. Lastly, sleep was significantly correlated with RHR, daily strain, and recovery. Findings such as correlations between sleep and RHR are in line with what previous literature has shown (Sekiguchi et al., 2019).

On average, the participants did not meet their recommended sleep. The average difference in actual sleep vs. sleep need (change in sleep) for the total population was -2.02 hours. Additionally, the average amount of sleep across the entire population was 6.89 hours. In a study that investigated associations between sleep duration and academic performance in college students found that the average duration of sleep for the entire population was 7 hours and 8 minutes. To note, these college students were not athletes and had an average total sleep duration that was almost 1 hour greater (Okano et al., 2019). This is less than the previously recommended 7-9 hours of sleep for most people and especially athletes (Bird, 2013). Although no significant correlations were found between sleep and performance in this study, it is apparent that most athletes do not get enough sleep. Previous literature on college athletes have found associations between sleep and athletic performance. A study conducted at Stanford University looked at the association between sleep extension on measures of athletic performance in basketball players (Mah et al., 2011). Results of this study found that measures of athletic performance such as sprint time, shooting accuracy, and reaction time were all correlated with sleep extension (Mah et al., 2011). From Whoop indicators, less sleep led to worse recovery the following day (see Figure 5) ($p=0.0001$; $R^2=0.086$). With that, another interesting finding was that average recovery for the total population was 62.46% (see Table 2). Due to the limited research on wrestlers and lack of research on wrestlers wearing Whoop, it is hard to compare, but generally, wrestlers would like to see their recovery be higher than this, especially leading up to competition. Since there is limited research using Whoop, it is hard to verify its usefulness in college athletes. With that, one study investigated the impact of Whoop technology on sleep, recovery, and performance of NAIA baseball players (Harms, 2018). In this study, participants found the technology to be of help in learning about their sleep, recovery, and performance (Harms, 2018). Specifically, some athletes mentioned that "'The main things I learned or felt was that when I got a recovery score above 90% my body felt great! But then if I got a 90% or below my body didn't feel that great at all.'" (Harms, 2018).

Another interesting finding recorded from Whoop was the percentage of strain that was estimated from their workouts. The total average percentage of strain from workouts for the total population for the entire study was 69.15%. Over half of daily strain came from exercise and training which ultimately was correlated with less sleep, lower RHR, and lower vertical jump height (see Figures 8, 10, and 11). Whoop uses daily strain to help calculate recommended sleep need each night. On days when participants had higher strain, Whoop acknowledged that and increased their recommended amount of sleep needed. This is seen in the negative association that strain had on the change in sleep (see Figures 8 and 9).

An interesting finding from the results showed that daily strain was associated with RHR. As daily strain increased, RHR decreased. This may insinuate that when daily strain was higher, a training adaptation occurred causing RHR to decrease. This information is beneficial for coaches and athletes to see if they are making progress or are getting in better shape. Other associations found were those between RHR, sleep, and change in sleep. Results showed that as duration of sleep increased, RHR increased (see Figure 12). Or vice versa, as RHR increased, sleep time increased. Like sleep duration, as the sleep deficit decreased or got closer to their sleep need, RHR also increased. This is surprisingly in line with what previous literature says about RHR and sleep (Sekiguchi et al., 2019). This may indicate that there was a higher demand for physical and maybe mental restoration and more sleep was needed to ensure recovery. To add, another study conducted to understand variability of RHR and its associations with age, sex, BMI, and sleep found that there was an association between daily sleep duration and RHR (Quer et al., 2020). The minimum RHR came from participants who had an average sleep duration of 7-7.5 hours per night (Quer et al., 2020). Participants who had an average sleep duration that was less than or greater than 7-7.5 hours per night tended to have higher RHR on average (Quer et al., 2020).

The role that hydration played in performance and other readiness indicators from Whoop was investigated. No significant correlations were found between fluid intake and performance or Whoop measurements, but data found from the BEVQ-15 survey alone was interesting. The average daily fl. Oz. consumed for total beverages was 99.18 fl. Oz. with a wide variety of fluid intake among the 9 participants. It is important to note that of the 9 participants, they wrestle in weight classes from 125lbs to 285lbs, with many in between. With this, wrestlers will have different hydration needs and habits based on weight, and some may even be managing their weight for competition on the weekend. This often plays a big role in the amount of fluid consumed by wrestlers and more research should be done on hydration and weight management tactics of wrestlers. Previous literature has found that wrestlers are often dehydrated when managing weight in season and in the off season during training (Buford et al., 2006). From statistical analysis, there was a negative trend between fluid intake and RHR, but a larger sample size is needed to see significant correlations. Another interesting finding was that results of the survey showed that multiple participants consumed 0 fl. Oz. of sugar sweetened beverages. This is not only important for athletes but for all people as well. A wealth of health promotion information points to drinking less sugar sweetened beverages to reduce the risk of obesity and other chronic diseases (Hu & Malik, 2010) (Hert et al., 2014) (Bélanger-Gravel et al., 2022). Additionally, since wrestlers are typically conscious of their calorie intake, especially during season, it was interesting to see that the average total kcals for total beverages consumed was 277.99 kcals.

Another variable measured in the study was the self-reported POMS questionnaire. No significant correlations were found from the POMS questionnaire either, but the self-reported mood profiles were important to see by themselves. The POMS questionnaire was scored using 7 subscales: Fatigue, anger, vigor, tension, esteem, confusion, depression, and total mood disturbance (Grove & Prapavessis, 1992). Higher total mood disturbance scores represent a more negative emotional state or a greater mood disturbance (Grove & Prapavessis, 1992). The POMS questionnaire was used to see potential relationships between mood states and other variables such as recovery and performance. No significant correlations were made between any of the POMS subscales or total mood disturbance and other Whoop related variables or the vertical jump. Further, it was considered that wrestlers may be stoic individuals who don't let extreme mood swings impact their performance or daily activities as much as others. It was refreshing to see that total average scores for the entire population for the subscales anger and depression were both under 1.00 at 0.58 and 0.21, respectively. Additionally, the average total mood disturbance for the entire population was 88.35. Lower scores represent more positive mood profiles or less mood disturbance. For example, Grove & Prapavessis (1992) studied mood profiles of 45 female netball players after winning outcomes and after losing outcomes. Results found that after winning outcomes the average total mood disturbance was 84.04 compared to after losing outcomes where the average was 109.71 (Grove & Prapavessis, 1992). As expected, losing outcomes produced a higher mood disturbance and a more negative mood profile than the winning outcome.

Since Whoop uses indicators such as RHR, HRV, and sleep to help calculate recovery and strain, it makes sense that there would be some association between these measurements. Recovery was positively associated with HRV. This means that as recovery increased, HRV also increased. This is in line with previous literature in that athletes who undergo a steep increase in training intensity have lower HRV and athletes who have higher HRV tend to be more recovered and can handle mental and physical stress better (Kamandulis et al., 2020). Additionally, RHR was negatively associated with recovery. This means that as the percentage of recovery increased, RHR decreased. This is a favorable adaptation. Based on literature, lower resting heart rate indicated better cardiorespiratory fitness and, in this case, better recovery from training (Gonzales et al., 2020). As hypothesized, sleep was positively associated with recovery. Meaning as duration of sleep increased, percentage of recovery the next day increased as well. It is interesting to see, however, the sleep deficit (average of -2.02 hours; see Table 2) the participants had over the course of the study. The closer participants were to meeting the Whoop measured sleep need, the better recovery they had the next morning.

Using data from the vertical jump test, as a measure of performance, correlations between variables such as HRV, RHR, recovery, sleep, hydration, mood state and more were investigated. The results showed that there was a significant correlation between daily strain and vertical jump height (see Figure 11). As daily strain increased, vertical jump height decreased. Although some outliers did exist and not all participants were able to complete the vertical jump test, enough data was available to point to an important association. This may suggest that when daily strain was greater, vertical jump height was lower and could be an indication of fatigue from acute increased training load. Previous research found that vertical jump height did not change significantly with increased training load but that increased training load may affect some aspects of performance (Callister et al., 1990). It is important to note that vertical jump was only tested once a week while strain was calculated daily on the Whoop app.

Strengths and Limitations

This study was conducted with highly competitive D1 collegiate wrestlers during in-season training. There are very few studies that use Whoop technology with collegiate athletes and to the author's knowledge this is one of the first studies that includes D1 college wrestlers using Whoop.

Although this study was a success and was novel, there were some limitations. First, a limitation of this study was that there were only 9 participants at the conclusion of the study. Small sample size limited our ability to make more correlations during statistical analysis. A larger sample size would be beneficial to see more associations between variables studied. Secondly, compliance was an issue across the board. Multiple participants did not fill out the POMS questionnaire each week. Additionally, some participants were incapable of doing the vertical jump test due to injuries. Lastly, of greatest priority was non-compliance with wearing the Whoop strap. Multiple participants had missing data from multiple days in a row and one participant had to be cut from the study due to lack of useable data. To add, there was no control over external circumstances of participant's daily decisions such as sleep, school, hydration, and training load. In addition to small sample size and compliance, another limitation was that there was no baseline data to compare against. Many studies in this field use randomized control trials to compare two groups. An example of a research design might look something like a non-training group compared to a training group that engaged in interventions such as a specific training regimen, different hydration habits, or a specific amount of sleep. This would be useful in seeing where the indicators researched deviated from baseline conditions. Finally, the last limitation was that this study only included males. It would be beneficial to see future research using both males and females wearing the Whoop strap.

Conclusion

The usefulness of Whoop technology to help athletes and coaches make training adaptations and increase performance is promising. From this study, Whoop technology wearable devices were generally found to be feasible to assess changes in performance and readiness indicators over the course of 3 weeks during in-season training for college wrestlers. Results found that recovery, as measured by the Whoop, was positively associated with HRV and sleep, but negatively associated with RHR ($p<0.0001$, $p<0.0001$, and $p=0.003$ respectively). HRV was also found to be negatively associated with RHR ($p<0.0001$). Daily strain was negatively associated with sleep, RHR, and vertical jump height ($p=0.021$, $p=0.0002$, and $p=.037$ respectively). Lastly, sleep was positively associated with RHR ($p=0.041$). However, more research on this topic needs to be done and future research with Whoop technology should aim for larger sample sizes to help derive more associations between variables measured.

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