OPTIMIZED ACUTE WORKLOAD COMPUTATION FOR BASEBALL PITCHERS: COUPLED 9-DAY EXPONENTIALLY WEIGHTED AVERAGES WITH DYNAMIC DIVISORS

Ben Hansen, Motus Global, Inc., Rockville Centre, NY

INTRODUCTION: Acute:chronic ratios (ACR) computed from workload gathering devices offer athletes, coaches, practitioners and performance staff a valuable and actionable measure of player fatigue. Defined as a ratio, ACR is generally calculated by dividing a player's acute workload (recent average of workload) by a player's chronic workload (longer-term average of workload). While the concept is straight-forward, there are a variety of methods to compute acute and chronic workloads, and there is much debate on how to calculate a single day's workload.

This white-paper outlines the analysis of acute:chronic ratios that are optimized for the sport of baseball using an injury dataset of 170,000 throws as well as a case study from a professional baseball pitcher.[1]

CALCULATING DAILY WORKLOAD: Powered by the motusTHROW sleeve, users have the ability to capture peak valgus torque from every throw made during practice and competition. The validity and reliability of the motusTHROW sleeve have been evaluated by internal and third party peer-reviewed studies and have been categorized as "excellent".[2,3,4]

Daily valgus workload (DVL) is calculated as an exponential sum of peak valgus torque from each throw in a given day, and is modeled after NASA's Daily Load Stimulus.[5]

$$Daily\ Valgus\ Load = \sum \left(\frac{\tau_{valgus}}{ht * wt}\right)^{1.3}$$

Many practitioners recommend incorporating previous days' workloads into a daily load measure via exponentially weighted moving averages (EWMA).[6] However, this does not allow for athletes to learn an association of a day's effort with a quantified workload number in an intuitive fashion. Therefore, the Motus platform only includes work from a given day in that day's DVL calculation. The Motus platform, however, does include exponentially weighted moving averages within the acute workload computation.

CALCULATING WEIGHTED ACUTE WORKLOAD: Acute workload in the Motus platform calculates an exponentially weighted moving average of the previous 9 days of workload starting with the kernel below.

$$Acute\ Kernel\ (AK) = [0.7, 0.77, 0.83, 0.90, 0.97, 1.03, 1.10, 1.17, 1.23, 1.3]$$

Using this kernel, workloads from most recent day are multiplied by a 1.3, and workloads from previous days are multiplied by lower magnitudes, such that 8 day before most recent day are multiplied by 0.7.

Next, when computing the weighted average, all weighted values must first be summed. From here, the sum must be divided by a number of days, "N". In standard fashion, the N = 9 days; however, in an effort to make ACR's more usable within the first 2 weeks of usage, a dynamics divisor is incorporated. In this case, on the first day of usage, the acute N is equal to 3 days. On subsequent days, N is incremented until 9 days of usage occur.[7]

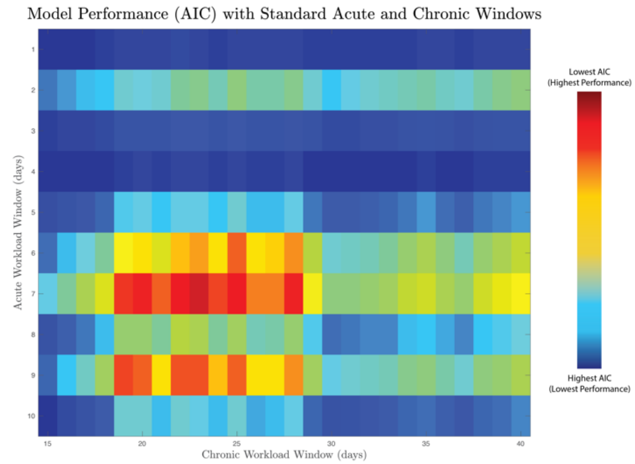
$$WL_{Acute} = \frac{1}{N} \sum_{day=0}^{day=-8} AK_{8-day} * DVL$$
$$N\ ranges\ from\ 3\ to\ 9\ days$$

SELECTING NINE DAY COUPLED ACUTE WEIGHTED AVERAGE: The majority of ACR calculations are done with an acute workload range over a period of seven days.[8,9] However, several studies have questioned the most appropriate range of days to include in an acute workload calculation, especially when considering the effects of scheduling in various sports.[11] Carey et al found that optimal injury risk models were realized when acute loads were calculated with either 3-day or 6-day windows, and when chronic loads were calculated with 21-day or 28-day windows.[10] However, this was using GPS data of moderate velocity running in the sport of Australian Football. Another method to alter the range of days included in an acute workload calculation, is to de-couple (or remove) the workloads used in the acute calculation from the chronic calculation.[12] This can be accomplished, where (e.g.in a standard 7-day acute/ 28-day chronic computation) the acute workload averages the last 7 days of daily load and the chronic workload averages the daily workloads between 35 and 7 days ago (spanning 28 days).

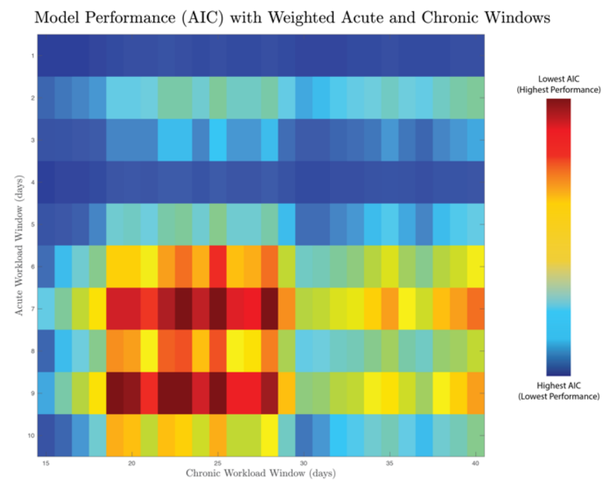
An analysis to evaluate all methods above, was done using an injury-tagged dataset of 1,500 baseball athletic exposures, consisting of 7 injuries in a high school baseball population with 170,000 throws captured from 18 players in one competitive spring season. All players wore the motusTHROW sleeve for all practice and competition.

First, ACR's were computed from parameter sweeps of acute and chronic loads, where acute time windows varied from 3-10 days, and chronic time windows varied from 10-40 days.

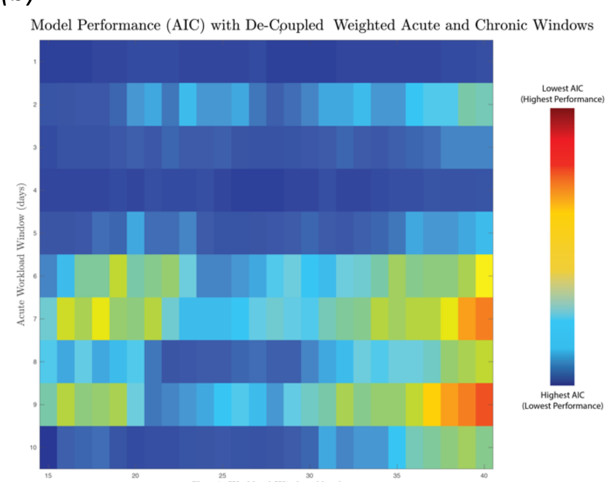
The parameter sweep was computed for three variations of acute workload calculations: (a) standard rolling average, (b) weighted rolling average, and (c) de-coupled weighted rolling average. For each of the total 1,380 combinations of ACR calculation, a logistic bi-nomial regression model was computed and the AIC value was reported for goodness-of-fit. All models were created using the R statistical programming language (R Core Team: R, Vienna, Austria 2018).



(a)



(b)



(c)

Figure 1. Heatmap of AIC with various acute workload calculation methods (a) standard rolling averages, (b) weighted rolling averages, and (c) de-coupled weighted rolling averages.

As seen in Figure 1- the highest performing models are achieved with the weighted rolling averages, not the standard rolling averages nor the de-coupled averages.

The highest performing models are achieved when the acute workload time window is either 7 or 9 days, and when the chronic workload is 25 or 28 days.

Furthermore, when taking into consideration the real-world scenario of pitching rotations, a 7-day time window is not sufficient. Under ideal conditions, a MLB pitcher may pitch every 6th day as part of a 5 man rotation. Often times, rest days are introduced into schedules, pushing starts to every 7th day. At the minor league and college levels though, this is much more frequent, with starts occurring once every 8-days.

In one example of a MiLB pitcher in Figure 2, the limit of using a 7-day window for acute workload computation is clearly evident. When the pitcher was on a regular schedule of pitching every 7th day, the acute workload contained 2 starts and five mid-week workouts. In this ideal case the spike in daily workload was reflected in the 7-day window of ACR.

However, when a rest day is introduced due to travel and off-days, the two starts are now 8 days apart, with six mid-week workouts. In the dataset below (Figure 2), this happened on the week preceding the start on April 15th. While the other three starting appearances were within 7-day acute windows and resulted in spikes in the ACR, the start on April 15th that spanned 8 days resulted in an ACR of less than 1.0 (blue dotted line).

Only when the acute workload method was changed to include up to 9 days with an exponential weight in the average, were all four starts properly flagged with spikes in the ACR.

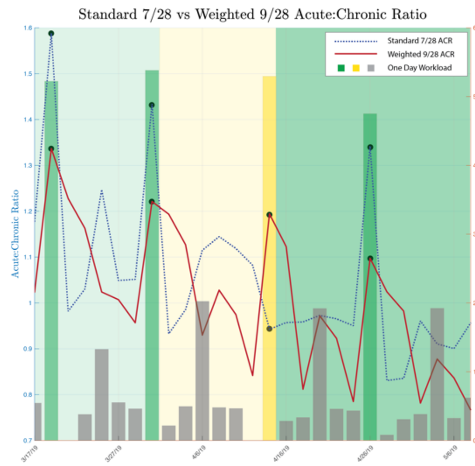


Figure 2. 7-day Standard vs 9-day Weighted ACR for 4 MiLB pitcher starting appearances. Green shaded starts fell within 7 days of each other and yellow shaded starts fell within 8 days of each other. The dotted blue line represents ACR from standard 7/28 rolling averages and the magenta solid line represents ACR with exponentially weighted 9 day acute rolling averages.

CHRONIC WORKLOAD SELECTION: Selection of an optimal chronic workload window is a multi-faceted problem. To begin, the weighted acute simulation showed that the ideal chronic workload window ranged from 21-28 days, with a tendency towards model improvement as the chronic window approaches 40 days. However, in order to enable actionable insights gathered from data in real-world settings, workload designers and performance staff need shorter initialization periods. For this reason, shorter chronic windows (28 days) are preferred. For this same reason, de-coupling the acute workload arrays from the chronic workload arrays is not preferred, as it only extends the initialization window and doesn't seem to provide a strong improvement in model performance.

Further analysis is needed with longer-duration datasets to investigate physiological relevance of chronic load windows that exceed 40 days. Given that anecdotal evidence from pitchers places workload limits on the scale of seasonal innings pitched, a 100+ day chronic load analysis may be appropriate.

CONCLUSION: Choosing optimal time windows and specific methods for computing acute and chronic workloads are critical for maximizing sensitivity of ACR. In baseball pitching, ACR is maximized for injury detection when the acute and chronic loads are coupled, while computing a standard 28-day rolling average for chronic load and an exponentially weighted 9-day rolling average for acute workload, both with dynamic divisors. Combined, the model selection allows for potent injury detection sensitivity and shortened initialization periods to enable actional insights as soon as possible.

REFERENCES

1. Mehta, Sameer *"Investigating the relationship between workload and throwing injury in elite, baseball athletes",* Physical Therapy in Sport, 28(3-4) November 2017
2. Dines, J, et al *"The Relationship of Throwing Arm Mechanics and Elbow Varus Toqrue: Within-subject Variation for Professional Baseball Pitchers across 82,000 Throws"*, Orthop J Sports Med, 5(7) July 2017
3. Boddy, K, et al *"Exploring wearable sensors as an alternative to marker-based motion capture in the pitching delivery"*, PeerJ, 7(e6365) January 2019
4. Melugin, H, et al *"Baseball Pitchers' Perceived Effort Does Not Match Actual Measured Effort During a Structured Long-Toss Throwing Program"*, Am J Sports Med, May 2019
5. Genc, K, et al *"Using the Enhanced Daily Load Stimulus Model to Quantify the Mechanical Load and Bone Mineral Density Changes Experienced by Crew Members on the ISS"*, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090034155.pdf
6. Murray, N, et al *"Calculating acute:chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages"*, Br Journal of Sports Med., 51(9) April 2017
7. Hansen B, et al *"Dynamic Divisors: A guide to using acute:chronic ratios sooner",* Motus Global, November 2018
8. Hulin, B, et al *"The acute:chronic workload ratio predicts injury:high chronic workload may decrease injury risk in elite rugby league players"*, Br. Journal of Sports Med, 50(4), January 2016
9. Bowen L, et al, *"Spikes in acute:chronic workload ratio (ACWR) associated with a 5-7 times greater injury rate in English Premier League football players: a comprehensive 3-year study"*, Br. Journal of Sports Med, February 2019
10. Carey D, et al, *"Training loads and injury risk in Australian football—differing acute:chronic workload ratios influence match injury risk"*, Br. Journal of Sports Med., 51(16) July 2017
11. Bornn, L, et al "Training Schedule Confounds the Relationship between Acute:Chronic Workload Ratio and Injury", MIT Sload Sports Analytics Conference, March 2019
12. Lolli L et al *"Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations",* Br. Journal of Sports Med. November 2017

