White paper

Health Score

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Contents

1. Executive Summary

The Teton One Health Score is a wellness monitoring tool that translates five evidence-based health metrics into a single, interpretable score ranging from 0 to 100. This framework helps care teams identify patterns, detect meaningful changes, and prioritize residents who may benefit from closer attention—without requiring wearables or physical contact.

What it measures: The score combines walking speed, respiratory rate, sleep duration, sleep regularity, and stationarity (time spent inactive in bed or seated). These five metrics were selected because they are always measurable with Teton One's remote monitoring system and have demonstrated associations with mortality outcomes in peer-reviewed research on older adults.

Why these metrics matter: Each metric serves as a window into different aspects of resident health. Walking speed reflects physical function and cardiovascular fitness. Respiratory rate signals potential cardiovascular or respiratory stress. Sleep duration and regularity indicate restorative health quality. Stationarity captures overall activity levels and time spent sedentary. Together, they provide a balanced view of both active and restorative health.

How it works: Raw measurements are converted to scores using simple piecewise linear functions based on clinically meaningful thresholds identified in the literature. All five components are weighted equally and averaged into a single score. Sleep regularity uses 48 to 96-hours of data, the other four components use 24 hours.

What it is — and isn't: This is a wellness monitoring tool designed to support care teams in tracking longitudinal patterns and facilitating conversations about resident well-being. It is not a medical device, diagnostic instrument, or clinical decision-making tool. Scores should complement—never replace—professional clinical judgment, physical examination, and comprehensive health assessment. Low scores may warrant attention, but the nature and urgency of any intervention must be determined by qualified healthcare professionals.

Scientific foundation: The framework is grounded in systematic review of peer-reviewed cohort studies with quantifiable mortality outcomes, focusing primarily on adults aged 60+ with follow-up periods of 3+ years. Every threshold and optimal range is derived from published hazard ratios and relative risk data, prioritizing high-quality research with large sample sizes (>500 participants or meta-analyses).

2. Introduction

In this document, we aim to describe how Teton One's health score works.

First, we will clarify the scientific literature used in the design process, both how these papers were identified and detailing the highlights from each. Then, we will show how this research is adapted to fit the Teton One use case and summarized into a health score, and finally, we will comment on some of the caveats and limitations with an aggregated metric like this score.

3. Methodology

Our goal was to develop a health assessment tool grounded in empirical evidence rather than conventional health assumptions. We systematically reviewed research to identify daily, measurable behaviors with demonstrated associations to overall health in older adults. All identified metrics must always be measurable with Teton without taking special cases and rules into account. The overarching goal is to develop a health score that can be easily interpreted and directly translated to actions to improve resident health.

We chose the research used in this report with a few criteria in mind:
- Focus on peer-reviewed studies with quantifiable mortality outcomes (like hazard ratio or relative risk)
- Prioritize cohort studies with >500 participants, or large-scale meta-analyses
- +3-year follow-up period

The population focus was primarily on 60+ year olds and preferably community dwelling. We strived to find research that results in a geographically diverse subset of participants, but prioritized high-quality research at all times. All research was required to have quantifiable measures of risk and clinically meaningful thresholds.

4. Core metrics

Monitoring health with technologies like wearables, smartphones, and other digital devices is a well-documented way to track a plethora of metrics to quantify personal health over time. The Teton One does not utilize wearables as everything is tracked remotely, with no physical contact required. Consequently, we cannot track the same parameters as a high-end smartwatch can, and not in the same quality as a medical device either.

The core metrics were chosen because they can be continuously measured with Teton One's remote monitoring system. Importantly, missing data itself provides information—for example, no walking speed data indicates a resident has not been mobile, potentially signaling health decline or an adverse event. [1].

The five metrics are: walking speed, respiratory rate, sleep duration, sleep regularity, and stationarity. These capture both active health (mobility and activity levels) and restorative health (sleep quality and recovery patterns).

4.1. Walking speed

Walking speed (gait speed) is a strong all-cause mortality indicator, especially for the 60+ age group. Fast and stable walking requires good bodily control and can be considered a simplified aggregate indicator of multiple organ systems, nervous, and musculoskeletal systems. Traditional methods for measuring walking speed are simple to do and provide effective results, so it's no surprise it's a widely applied way to estimate physical function. [1], [2], [3].

Chen et al. carried out a 3-year prospective study of 558 institutionalized men (75+ years) in Taiwan and found that walking speed was a powerful predictor of mortality. Men in the slowest quartile (<0.67 m/s) faced a 3.55-fold higher risk of all-cause mortality and an 11.55-fold higher risk of cardiovascular death compared to those walking >1.0 m/s. Walking speed remained a consistent predictor even after adjusting for age, co-morbidities, and other physical performance measures with a Cox analysis and proved superior to handgrip strength for predicting all-cause mortality in this population. Within the 3-year follow-up period, 99 participants died. To measure walking speed, participants were asked to walk 6 meters in their habitual pace, where the shortest walking period of 2 trials was selected. [3].

Studenski et al. analyzed a pool of 34,485 community-dwelling adults aged 65+ from 9 cohort studies, followed for 6-21 years, and found that each 0.1 m/s increase in gait speed was associated with a 12% reduction in mortality risk (HR 0.88). Gait speed and mortality risk demonstrated a continuous and predictable relationship across the full range: at age 75, predicted 10-year survival ranged from 19% to 87% in men and from 35% to 91% in women, depending on walking speed. The predictive accuracy of age, sex, and gait speed for survival was equivalent to more complex models incorporating multiple chronic diseases, blood pressure, BMI, and hospitalization history. Gait speeds above 1.0 m/s consistently predicted longer-than-expected survival, while speeds below 0.6 m/s indicated significantly increased mortality risk.

4.2. Respiratory rate

Respiratory rate is a significant indicator of different pathological conditions and stressors, but is not routinely monitored in care homes or hospitals, especially not continuously throughout sleep as a nocturnal monitoring metric [4]. With the Teton One, respiratory rate can be estimated for every night's sleep and used as an indicator of changes in health state.

Baumert et al. studied nocturnal respiratory rate as a predictor for cardiovascular and all-cause mortality in community-dwelling older men and women (65+ years old) from the U.S. Men and women were studied in individual groups. All participants were recruited from osteoporotic fractures studies. 2686 men were studied with a 9-year follow-up, and 406 women with a 6-year follow-up, both using overnight home-polysomnograms. Mean nocturnal respiratory rate was 14.8 ± 1.8 brpm for men, and 15.5 ± 1.7 brpm for women. Using a Cox regression, they found that a nocturnal respiratory rate ≥ 16 brpm was significantly associated with both cardiovascular mortality (men: 9 years, women: 6 years) and all-cause mortality (men: 14 years, women: 6 years) [5].

Barthel et al. investigated daytime respiratory rate as a mortality predictor in acute myocardial infarction survivors (mean age 61 years) from Germany. 941 consecutive patients were studied with a 5-year follow-up, using standardized 10-minute resting recordings within 2 weeks post-MI. Measurements were obtained via piezoelectric thoracic sensors during supine rest. Using multivariable Cox regression adjusted for GRACE score [6], left ventricular ejection fraction (LVEF), and diabetes, they found that respiratory rate was an independent predictor of mortality (HR 1.14 per 1 brpm increase), with each 4 brpm increase doubling mortality risk. Among high-risk patients (GRACE score $\geq$120), those with RR $\geq$ 20 brpm and LVEF $\leq$ 35 percent had $>$ 50 percent 5-year mortality, while those with RR $<$ 20 brpm and LVEF $>$ 35 percent had $<$ 10 percent mortality.

It is worth noting that respiratory rate tends to increase with age, but so does the mortality risk. One study found the mean respiratory rate to be 16.1 ± 4.28 brpm for 634 Japanese participants (59 - 100 years old), though the correlation between age and respiratory rate was only $R = 0.17$ (Pearson's correlation) [7].

4.3. Sleep

Sleep has long been known to play an important role in health as we age, especially our cognitive function. Traditionally, sleep duration has been the most important factor to track, but with the massive increase in the variety of wellness and fitness trackers, sleep stages have started playing a major role too, where some combinations of sleep stages supposedly produce the optimal sleep quality [8], [9]. Teton One cannot estimate sleep stages. Sleep-related parameters like number of wake-ups during sleep, perceived sleep quality, sleep latency, and sleep regularity seem to be strong indicators of all-cause mortality.

Sleep regularity was recently found to be a stronger all-cause mortality indicator than sleep duration in a prospective cohort studied by Windred et al. 60,977 UK Biobank participants (mean age 62.8 years, 55.0% female). Sleep Regularity Index (SRI) scores were calculated from >10 million hours of 7-day accelerometer recordings (median SRI 81.0, IQR 73.8-86.3). During 6.3 years of follow-up, 1,859 participants died (1,092 cancer, 377 cardio metabolic). Using multivariable Cox regression adjusted for age, sex, ethnicity, physical activity, and sociodemographic/lifestyle/health factors, the top four SRI quintiles showed 20-48% lower all-cause mortality (highest quintile: HR 0.70, p<0.001), 16-39% lower cancer mortality, and 22-57% lower cardio metabolic mortality versus the lowest quintile. Sleep regularity was a stronger predictor than sleep duration by model comparisons (AIC p=0.005; likelihood ratio p=0.14-0.20) and remained significant when both were included in the same model.

Morgan & Hartescu studied sleep duration and all-cause mortality in 960 UK older adults (65+) with a 27-year follow-up (927 deaths). Sleep duration was calculated from reported bedtimes, rise times, and sleep latencies. Long sleep (≥9h) predicted mortality adjusted for demographics, health, and lifestyle (HR 1.37, 95% CI: 1.05-1.78, p=0.02 vs 7h reference). When frailty indices were added, long sleep became non-significant (HR 1.18, p=0.32), while low physical activity (HR 1.79, p<0.01) and very slow walking speed (HR 1.41, p<0.01) remained significant predictors suggesting long sleep-mortality associations confound with frailty [10].

Itani et al. conducted a systematic review and meta-analysis of short sleep duration and health outcomes in 5,172,710 participants from 153 prospective cohort studies (minimum 1-year follow-up). Short sleep was defined primarily as <5 or 6 hours. Using random-effects models of adjusted data, short sleep was significantly associated with all-cause mortality (RR 1.12, 95% CI 1.08-1.16), diabetes (RR 1.37, 1.22-1.53), hypertension (RR 1.17, 1.09-1.26), and cardiovascular disease (RR 1.16, 1.10-1.23). Meta-regression found a linear association between shorter sleep duration and increased mortality at <6 hours (p=0.008) [11].

The American Academy of Sleep Medicine (AASM) and the Sleep Research Society (SRS) jointly issued a recommendation in 2015. This recommendation was based on an expert panel of leading sleep researchers who reviewed scientific evidence on the relationship between sleep duration and health for adults aged 18 to 60. The general recommendation is to aim for 7 or more hours of sleep per night consistently to promote optimal health. There is no upper limit to the recommended sleep duration. However, it is uncertain whether sleeping more than 9 hours per night is associated with health risks for adults in this age group [12]. This white paper focuses primarily on individuals over 60, so for our scoring framework, this recommendation does not necessarily apply. Additionally, consecutive extended sleep patterns can be indicators of frailty and other health complications, as suggested by the research mentioned above, so for a framework like ours, it makes sense to add an upper limit on sleep duration.

4.4. Stationarity

Stationarity is an aggregate metric combining time spent lying and sitting in bed, as well as sitting in a chair or couch. We combined in-bed time and in-chair time because it is important to track as much inactive time as possible and handle the most amount of edge cases. Spending too long in bed, especially without sleeping, is both detrimental to your restorative health, i.e. ability to fall asleep and sleep well, and your active health.

Yoshiike et al. analyzed 5,804 participants (3,128 middle-aged, 2,676 older adults) using polysomnography-measured total sleep time (TST) and time in bed (TIB), combined with sleep restfulness ratings, over a median follow-up of 11-12 years [13]. Among older adults (≥65 years), the highest TIB quartile (≥482 minutes/ 8 hours) was consistently associated with increased mortality compared to the inter quartile range, with a hazard ratio of 1.25 (95% CI 1.08-1.46) in fully adjusted models—this association persisted even after accounting for actual sleep duration. Most critically, when long TIB was combined with feeling unrested after sleep, mortality risk increased substantially to HR 1.57 (95% CI 1.23-2.01), representing a 57% increased risk of all-cause mortality. The quartiles were defined as < 404 minutes, 404 to 482 minutes, and > 482 minutes. The authors suggest that prolonged bed rest in older adults may cause physiological complications (decreased cardiac output, hypoxemia, muscle atrophy) and that the combination of long TIB with non restorative sleep indicates failed sleep homeostasis, distinguishing genuinely harmful "long sleep" from protective adequate sleep.

Chau et al. analyzed 6 prospective studies (595,086 adults, 29,162 deaths, 3.5 million person-years) and found a non-linear dose-response relationship between daily sitting time and all-cause mortality. After adjusting for physical activity, each additional hour of sitting showed hazard ratios of 1.00 (95% CI: 0.98-1.03) for 0-3 hours/day, 1.02 (95% CI: 0.99-1.05) for >3-7 hours/day, and 1.05 (95% CI: 1.02-1.08) for >7 hours/day, with adults sitting 10 hours/day having 34% higher mortality risk (HR=1.34, 95% CI: 1.28-1.40) compared to minimal sitting. Moderate-to-vigorous physical activity partially attenuated but not eliminating the hazardous associations, particularly at the highest sitting levels. [14].

5. Scoring framework

In this section, we will cover how each of the metrics is scored, and how those scores are combined into a single health score. The scoring functions have two goals: 1) be simple enough that they are easily explained, 2) maintain as much clinical relevance as possible. The metrics tracked by Teton One are in no way medical grade, and should not be treated as such. By using more advanced scoring functions, we can take more clinical data into account, but if these functions become overly complicated, then the aggregated health score becomes too complex to easily understand and end up sacrificing usability. We'll be using the research outlined in the previous section to identify optimal ranges for every metric, and develop a scoring function for each. To maintain high explainability, we will limit ourselves to only using piecewise linear scoring functions.

5.1. Components

In the following section, we will detail each of them, and argue for the specified ranges.

5.1.1. Respiratory rate

The studies on respiratory rate measured both nocturnal and daytime values, but the Teton One system primarily estimates nocturnal respiratory rate. A nocturnal respiratory rate ≥16 breaths per minute (brpm) was significantly associated with all-cause mortality. For daytime respiratory rate in high-risk cardiac patients, values ≥20 brpm (combined with reduced heart function) were significantly associated with increased mortality risk, and each 4 brpm increase doubled the mortality risk. We have visualized the scoring function on Figure 2 for respiratory rate, and defined the optimal respiratory range as 13-16 breaths per minute, with a relatively steep decline inspired by the 4 brpm doubling the mortality risk.

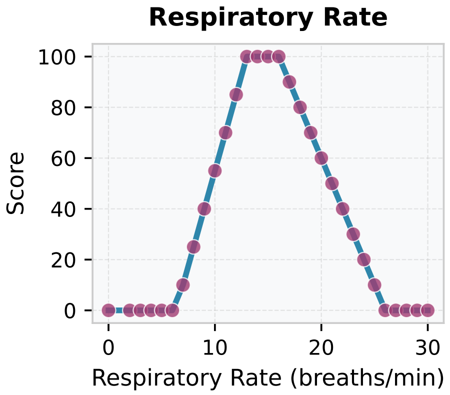

Figure 2: Respiratory rate – optimal ranges is 13-16 breaths per minute

5.1.2. Stationarity

Stationarity is our aggregate of time spent in bed (while awake or asleep) and time sitting in chairs or couches. Time in bed >8 hours (>482 minutes) was associated with 25% increased mortality risk, rising to 57% when combined with feeling unrested after sleep. The optimal range was 6.7-8.0 hours in bed. For sitting time, mortality risk increased significantly beyond 7 hours/day, with each additional hour adding 5% increased risk. Adults sitting ≥10 hours/day had 34% higher mortality risk compared to minimal sitting, even after accounting for physical activity levels. Residents do not spend their entire day in their homes, and are therefore likely to sit in places where Teton One cannot track them. Some residents are

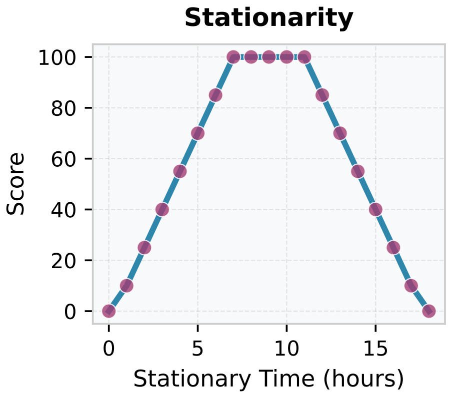

Figure 3: Stationarity – optimal range is 7-11 hours per day, broad range to handle residents spending a lot or a little time in their homes

also immobile and will be moved manually by staff from the bed to a chair. Some even sleep in chairs or couches. To accommodate all these edge cases, we've combined all those metrics into one, stationarity, and adjusted the optimal values to be relatively broad from 7-11 hours as seen on Figure 3.

5.1.3. Walking speed

Walking speeds ≥ 1.0 m/s were associated with better survival. Each 0.1 m/s increase corresponded to 12% lower mortality risk (HR 0.88). Speeds <0.6-0.67 m/s were consistently associated with increased mortality across studies. These walking speeds were all measured as a part of explicit walking speed tests, but the walking speed we estimate with Teton One is more stochastic and slower in nature, because they're from residents walking around in their homes. With this in mind, we designed the scoring function seen in Figure 4 with the optimal range extending down to 0.9 m/s to take slower in-home walking into account. The slope is slightly more steep after 0.6 m/s, as most studies defined this as the lower limit.

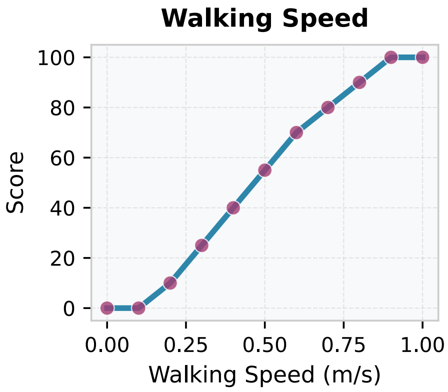

Figure 4: Walking speed – optimal range is 0.9-1.0 m/s, slightly steeper curve after 0.6 m/s as this was lower limit in most studies

5.1.4. Sleep duration

Sleep duration shows a U-shaped relationship with mortality risk in older adults ($\geq$65 years). Short sleep (<6 hours) was associated with 12% increased all-cause mortality, with linear increases in risk below 6 hours. Long sleep ($\geq$9 hours) was associated with 37% increased mortality, though this association may be confounded by frailty markers like low physical activity and slow walking speed. Scoring function is shown in Figure 5 with 7-9 hours being the optimal range.

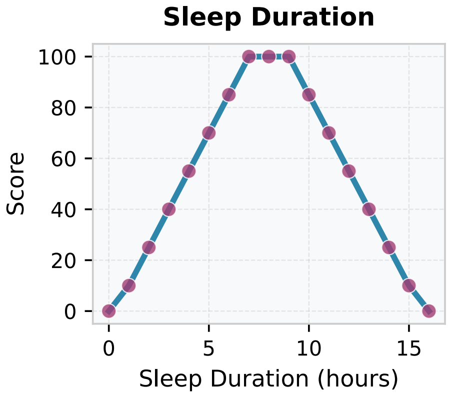

Figure 5: Sleep duration – optimal range is 7-9 hours per day

5.1.5. Sleep regularity

Sleep regularity, measured by the Sleep Regularity Index (SRI), reflects day-to-day consistency in sleep-wake timing. The study cohort had a median SRI of 81.0 (range: 2.5-98.5). Irregular sleep patterns (SRI $<$ 71.6) were associated with significantly higher mortality risk. Regular sleep (SRI $\geq$87.3) was associated with 20-30% lower all-cause mortality in fully adjusted models. Sleep regularity was found to be a stronger predictor of mortality than sleep duration in older adults. In line with ranges found in the study, we've defined 85-100% as the optimal SRI range, as seen on Figure 6.

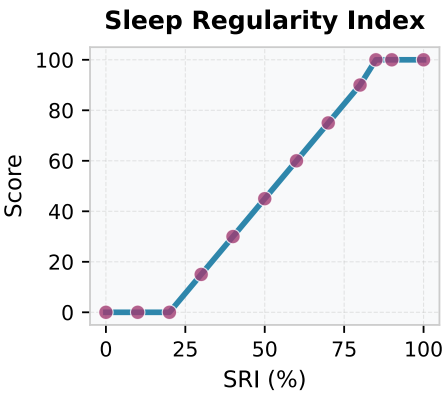

Figure 6: Sleep regularity index – optimal range is 85-100%

To compute a sleep regularity level, we require at minimum 48 hours of context, and at most 96 hours. We chose to go with 48 hours to increase the usability of the feature.

We penalize the score from the sleep regularity index if the person is sleeping less than 4 hours. This is not generally covered in the literature, but the sleep regularity index can be 100% even if the person is sleeping 30 minutes per day, but this is not meaningful in the context of a scoring framework. The penalized sleep regularity index is computed as $\mathrm{SRI} = \mathrm{SRI}_{\mathrm{raw}} \cdot \min\left(1, \frac{(\text{sleep duration [hours]})}{4 \text{ [hours]}}\right)$

5.1.6. Total score

To compute the total health score, all five elements are weighed equally and summarized into a single score from 0 to 100. The sleep regularity index is computed using up to past 96 hours of sleep data, minimum 48 hours. All other values use 24 hours of context.

To compute any score, the person must have been in bed at least 2 hours for each day in the 48 hour period, otherwise do not compute anything.

5.2. Examples

In this section, we will cover two examples based on real-world data from two different Danish care homes.

In Figure 7, we see the health score and its components tracked over time, from the end of May to the end of August. The five elements are stacked on top of each other, with the total health score marked by the black line. The score looks stable for most of the tracked period, but on August 23rd, a fall with a confirmed injury occurs. On the 29th of August, the resident moved out for an unknown reason, but the health score significantly declined with a combination of less time outside the bed, more irregular sleep, and suddenly changing respiratory rate in the period up to the move-out. This is one example of how a change in health was negatively impacted by a serious fall incident and was reflected in the health score. See all com

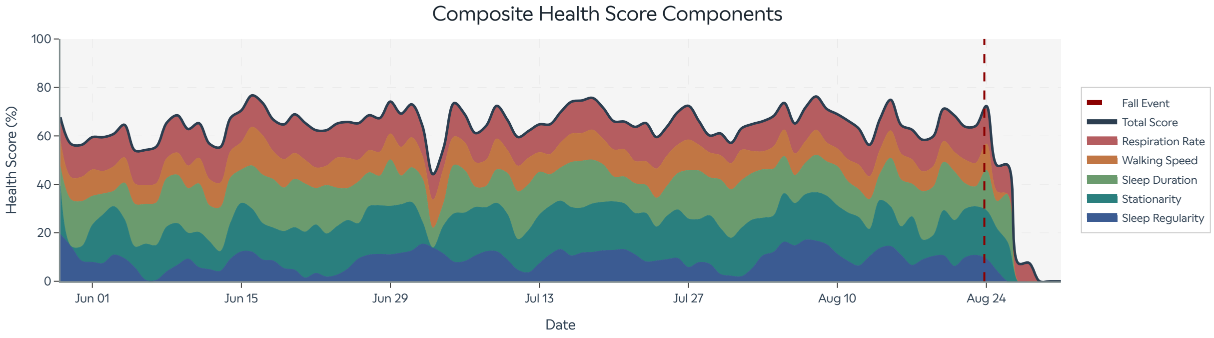

Figure 7: Example 1 – A serious fall occurred at the end of August, and the resident moved out of the care home on the 29th of August for an unknown reason. All metrics and their score can be found in Appendix A, Figure 9.

Another example is shown in Figure 8, where the health score was relatively stable for most of June, but a fall occurred at the end of June, introducing some instability afterwards. Right before the fall, the health score actually went down slightly. From the detailed plot in the appendix, Figure 10, we see that the respiratory rate increased in that period from a habitual range of 19-20 brpm all the way to 23 brpm during the night of the fall, potentially an indication of the resident being ill during this period. Over time, especially in October, the score actually starts improving again, indicating that the resident is doing better than at the end of June after their fall. We specifically see that the stationarity started to improve, indicating that they're spending less time in an inactive state.

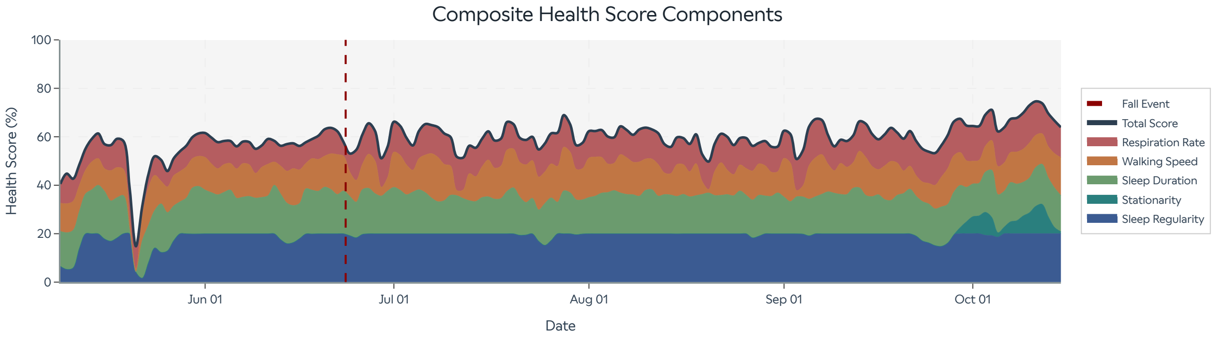

Figure 8: Example 2 – Health score improved over time, even after a fall. All metrics and their score can be found in Appendix A, Figure 10.

6. Limitations

While this health scoring framework is grounded in peer-reviewed research and designed for practical implementation, several important limitations must be acknowledged when interpreting and applying these scores.

The research studies cited in this report employed standardized protocols that actively prompted specific behaviors under controlled conditions, whereas Teton One passively observes these same metrics during spontaneous daily activities. For example, walking speed in the literature was measured by instructing participants to complete timed 6-meter walks at their habitual pace, while Teton One captures naturalistic walking patterns as residents move about their rooms without prompting or performance awareness. Each metric in the cited research was measured with medical device equipment, whereas Teton One is not a medical device.

Limitations like population and context generalizability, of course, also apply here. The research underlying this framework draws from diverse populations but focuses on community-dwelling older adults.

The 24-hour window will smooth out some spikes and variations in the contributors to the health score, but can also hide any smaller, meaningful variations. Teton One is a remote monitoring tool and must be treated as one, requiring more data cleanup and post-processing than contact-based alternatives.

This health scoring framework is designed as a wellness monitoring tool to identify patterns and trends in resident behavior over time. It is not a medical device, diagnostic instrument, or clinical decision-making tool. The score should not be used to diagnose medical conditions, guide treatment decisions, or replace standard clinical assessments and professional judgment. The appropriate use of this framework is to:

Support care teams in identifying residents who may benefit from closer attention or assessment. Track longitudinal patterns and detect meaningful changes from individual baselines. Facilitate conversations between care staff and healthcare providers about resident well-being. Complement—not substitute for—regular clinical evaluations, direct observation, and resident-reported concerns.

All clinical decisions must be made by qualified healthcare professionals based on a comprehensive assessment that includes, but is not limited to, physical examination, medical history, laboratory results, cognitive evaluation, and direct patient interaction. A declining health score may warrant clinical attention, but the specific nature and urgency of that attention must be determined by appropriately trained and licensed practitioners. Care teams should view this score as one data point among many in a holistic understanding of resident health. Low scores do not automatically indicate a need for medical intervention, and high scores do not guarantee the absence of health concerns. The framework is intended to augment human judgment and clinical expertise, not replace it.

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Appendix A

Example 1

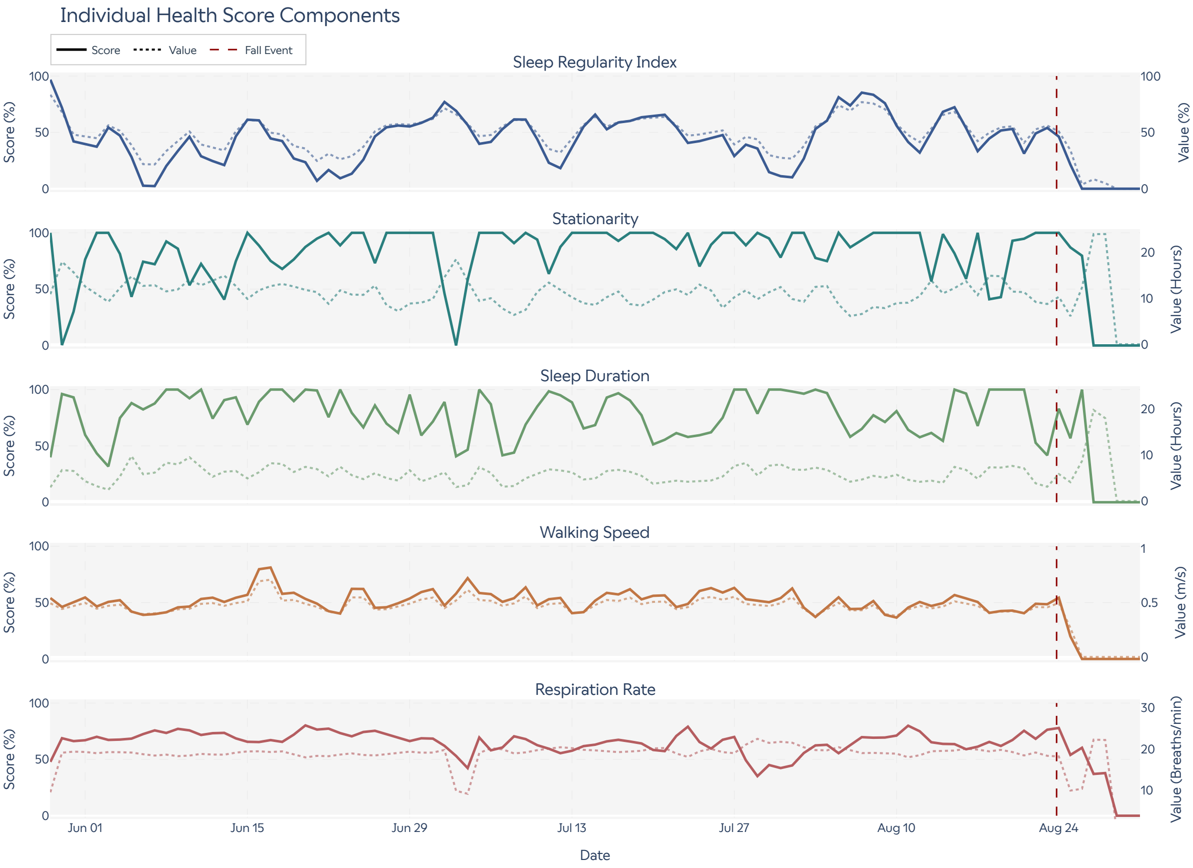

Figure 9: Detailed components of Figure 7. The solid lines are scores (left y-axis), and the dotted lines are actual values (right y-axis)

Example 2

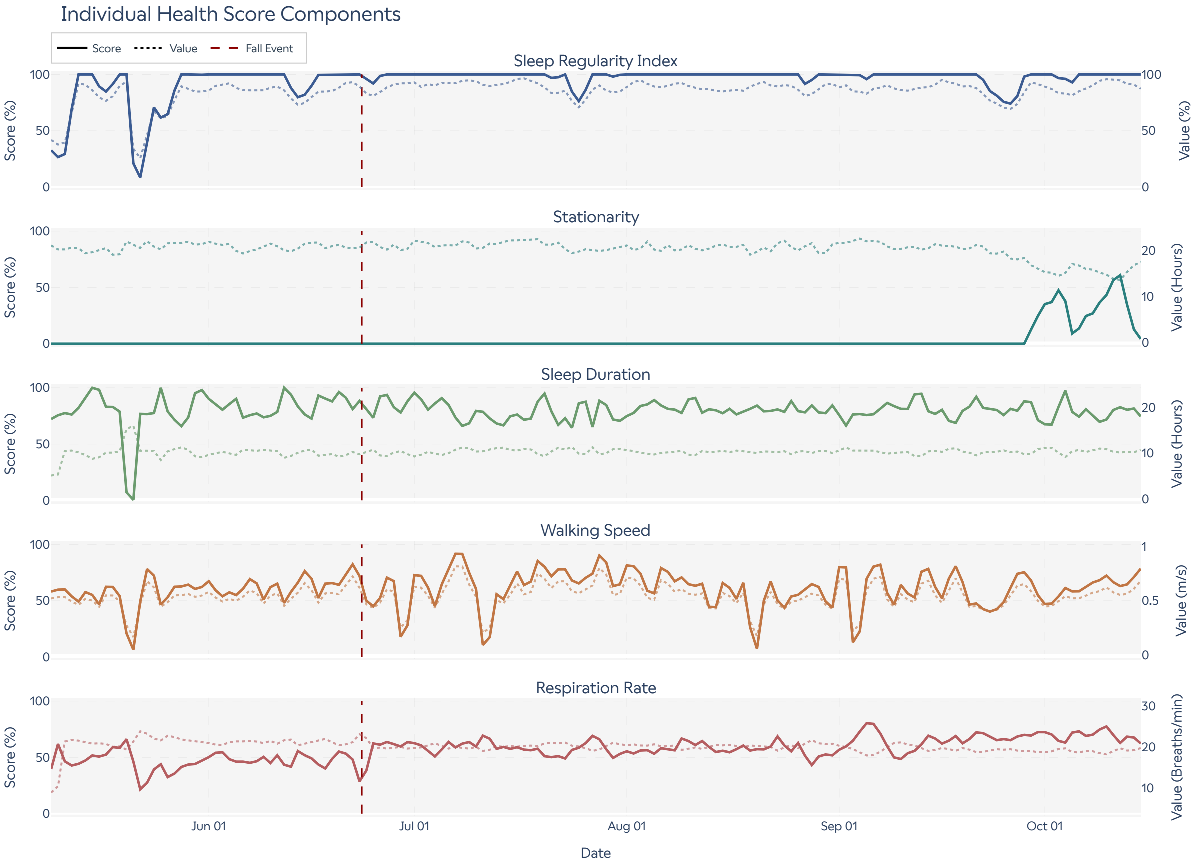

Figure 10: Detailed components of Figure 8. The solid lines are scores (left y-axis), and the dotted lines are actual values (right y-axis)