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ORIGINAL ARTICLE

Compliance to training load and heart rate variability monitoring in young Swiss judokas

EXERCISE IS MEDICINE

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Abstract

Introduction: Assessment of exercise training load (TL) can identify mechanisms of fatigue and injury. At present, techniques to monitor TL in young athletes are lacking.

Objectives: To examine the adherence to two monitoring techniques to assess TL among young judokas.

Methods: Over a 10 week study period, TL was assessed by completion of a daily training log and by weekly measurement of heart rate variability (HRV). The satisfaction to HRV method was assessed by survey at study completion.

Results: Among national caliber judokas (n=10, age 16 ± 2 y, weight 63 ± 5 kg, height 169 ± 8 cm,), training logs were completed at a 98 ± 5% rate, while HRV measurement was successful 57% ± 37%. HRV was comparable to young and athletic population. Difficulties in performing HRV measurements were rated 3.3 ± 1.9 (1: not constraining to 10: extremely constraining).

Conclusion: Excellent adhesion for training diary completion was only possible with regular demands from coaches for ratings. Judo seems to enhance cardiac autonomic control in young national level athletes. HRV monitoring compliance was suboptimal among young judokas and opportunities for future improvement are suggested by our data.

Resumé

Introduction: L'évaluation de la charge d'entraînement (CE) peut permettre d'identifier les mécanismes de fatigue et de blessure. À l'heure actuelle, les méthodes de surveillance de la CE chez les jeunes athlètes font défaut.

Objectifs: Examiner l'adhésion à deux méthodes de surveillance pour évaluer la CE chez des jeunes judokas.

Méthodes: Sur une période d'étude de 10 semaines, la CE a été évaluée en remplissant un journal d'entraînement quotidien et en mesurant chaque semaine la variabilité de la fréquence cardiaque (VFC). La satisfaction de la méthode VFC a été évaluée par une enquête à la fin de l'étude.

Résultats: Parmi des judokas de niveau national (n=10, âge 16 ± 2 ans, poids 63 ± 5 kg, taille 169 ± 8 cm,), les journaux d'entraînement ont été remplis à un taux de 98 ± 5 %, tandis que la mesure de la VFC a été

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collectée avec succès à un taux de 57% ± 37%. Le VFC était comparable à celle d'une population jeune et athlétique. Les difficultés rencontrées lors de la mesure de la VFC ont été évaluées à 3.3 ± 1.9 (1: pas contraignant à 10: extrêmement contraignant).

Conclusion: Une excellente adhésion au remplissage du journal d'entraînement n'a été possible qu'avec des demandes régulières de la part des entraîneurs. Le judo semble améliorer la variabilité de la fréquence cardiaque chez les jeunes athlètes de niveau national. L'adhésion du suivi de la VFC était sous-optimale chez les jeunes judokas et nos données suggèrent des possibilités d'amélioration future.

Mots-clés: Jeunes athlètes, judo, charge d'entraînement, variabilité de la fréquence cardiaque, fatigue

Introduction

Effective characterization of training load (TL), defined as the cumulative amount of stress placed on an individual from a single and/or multiple training sessions, integrates external load (i.e. work completed by the athletes quantified by duration and intensity) and internal load (i.e. the physiologic and psychologic stress imposed by activity and environment) [1]. Training load can be monitored by coaches to ensure positive adaptation while simultaneously minimizing the risk of non-functional over-reaching and overtraining syndromes [1]. In parallel, clinicians often analyze TL data to understand mechanisms of injury and overuse pathology [2]. Among young competitive athletes, excessive TL during a single season or over a total career may precipitate excessive fatigue leading to overuse injury and early retirement [3-5].

Among implemented TL monitoring methods, Foster's session rate of perceived exertion (sRPE), which estimates the intensity of a training session by multiplying duration with a subjective grade, is widely used due to its extreme simplicity [6,7]. Another internal load method presenting the advantage of being independent from athletes' conscious influence is heart rate variability (HRV) monitoring. With a supine and standing 5-minute morning measure, it is possible to verify TL physiological impact on athlete's ability to positively or negatively cope with it [8-10].

The use of TL monitoring among young competitive athletes is highly variable both across and within specific sporting disciplines. Factors contributing to this variability include perceptions regarding financial cost, time efficiency, precision of measurement, and ease of use [11]. Among youth coaches responsible for athletes of both genders and encompassing a wide range of chronologic and biologic age, inadequate time due to competing administrative tasks represents a primary barrier to implementation [12]. While other qualified team staff members including strength and conditioning coaches can assume responsibility for TL monitoring, such manpower is not routinely available at youth levels of sport. Completeness and thus precision of TL monitoring is also viewed as a barrier to implementation. For example, athletes often train with a primary club but also participate in regional or national performance center training and perform unstructured leisure time physical activity (eg. ski). In aggregate, these issues underscore the need to develop and assess simple, valid, reliable techniques to capture TL among young competitive athletes. Accordingly, this study was conducted to examine the adherence of TL monitoring among a small cohort of national caliber athletes. Specifically, we examined compliance with and data quality of weekly training load diary recording and heart rate variability monitoring.

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Methods

Design

This was a 10-week, prospective, observational study conducted in the framework of a cooperation between the CHUV Swiss Olympic Medical Center and a local judo club (Mikami Judo Club). Prior to data collection, we held an information session for athletes and their parents in order to present and explain two monitoring technique: Foster's sRPE [6] and morning HRV [8]. Athletes received guidance about how to complete a daily training log and how to perform HRV measurements during the duration of the study. At study completion, a satisfaction survey was performed using an online questionnaire. Each participant's legal representative signed an informed consent to participate in the study.

Training load

Each participant was assigned a Google Drive personal file that was accessible through their personal smartphone. This file included an Excel database where they were instructed to provide daily information describing the type(s), duration(s), and subjective perceived intensity(ies) of all sport activity performed within 30 minutes of completion (Figure 1). Foster's session-RPE (sRPE) were calculated by multiplying duration of activity by RPE [6]. Acute training load (ATL) was calculated as the average of the sRPE of the last 7 days. Chronic training load (CTL) was calculated as the average of the sRPE over the preceding 28 days. A simplified version (eliminating exponential weighted of moving averages) of the Acute:Chronic-Workload Ratio (ACWR) was calculated by dividing ATL by CTL [13-15]. After observing a less than desirable participation rate in the first 2 weeks, it was decided that athletes had to report their activities via Whatsapp to one of the main coaches, who filled the Excel file for each athlete.

Training intensity

10	Maximal
9	
8	
7	Very strong
6	
5	Strong
4	Somewhat strong
3	Moderate
2	Easy
1	Very, very easy
0	Rest

Figure 1: Subjective scale used for session-RPE calculation

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Heart rate variability

R-R intervals were collected using the following standardized conditions: 1) immediately upon waking on morning after rest days, 2) with no high intensity training 2 days before the measurement, 3) 5 minutes supine and 5 minutes standing up. HRV data was acquired using a heart rate monitor (H10, Polar Electro Oy, Kempele, Finland) and a dedicated smartphone based application (InCorpus, be.care, Lausanne, CH). Raw R-R intervals were extracted from the application and analyzed with Kubios Premium software (Kubios Oy, Finland). Specifically, we analyzed the last 4 minutes of each 5-minutes segment using medium filtering and an automatic correction algorithm [16]. All raw data were manually checked by one of the investigators. Time- and frequency-domain metrics were retained for analyses [17]. All HRV procedures were carried out in agreement with available Task Force recommendations [18]. All data with significant artifact or confounding factors (e.g. conditions not met, movements, high intensity training the 48h before measurement) were excluded from subsequent analyses. Coaches expected 10 measurements per athlete after a light training day or rest day during this 10-week period ($1 \cdot week^{-1}$).

HRV satisfaction study

The satisfaction study was done via a short online questionnaire at the end of the follow-up.

Statistical analysis

This study only presents descriptive statistics. Each training log variable, both for individual and grouped data, is presented as a mean value with standard deviations and range. For descriptive group HRV data, medians with 25^{th} and 75^{th} percentiles are used. Microsoft Excel® (2016; Microsoft Corporation, Redmond, WA, USA) was used for statistical analysis.

Results

Participants' characteristics

Participants included 8 male and 2 female young Swiss national level judokas *(Table 1)*. Two athletes were injured at the beginning of the study period but resumed training 3 weeks thereafter. In addition, one athlete sustained a traumatic finger injury necessitating abstention from training for 8 days within the study period.

Age (y)	15.5 ± 2 [12; 18]
F/M	2/8
Weight (kg)	62.5 ± 5.2 [56; 71]
Height (cm)	168.8 ± 8.1 [158; 181]
BMI ($kg \cdot cm^{-2}$)	22 ± 2 [19.2; 26.9]

Table 1: Participant's characteristics *Caption:* F, female; M,

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male. Data are presented as mean ± SD [min;max]

Training load

During the 10-week period, athletes reported 29 ± 8 [14;39] training units. There was a 2-week scholar holiday inclusive of study weeks 3 and 4 during which some athletes went on vacation and/or did not train. Also, this study was conducted in conjunction with the onset of the COVID-19 pandemic during which the practice of contact sports at the amateur level was prohibited from week 4 except for minors (group of 10 max). Participants mainly practiced judo but other sports were occasionally reported (strength training, running, squash, ski, football, basketball, cycling, skateboard). Training load variables are presented in *Table 2*.

Average of training units average duration (min)	93.9 ± 13.9 [76.8; 126.3]
Average of training units average RPE	5.9 ± 0.9 [4.2; 7.2]
Average of training units average sRPE	546.9 ± 111.4 [293.8; 695.8]
Average of average sum of sRPE per week	1569.1 ± 538.4 [711; 2182]
Average of average sRPE per unit per week	490.1 ± 126.6 [290; 630]
Average acute training load (Days = 64)	225.8 ± 75.7 [111; 114]
Average chronic training load (Days = 64)	229.6 ± 74.4 [114; 340.8]
Average ACWR (Days = 43)	1.26 ± 0.14 [1.08; 1.41]
Average of maximum ACWR (Days = 43)	2.52 ± 0.84 [1.61; 4.02]

Table 2: Main training load variables issued from training logs. *Caption:* Data are presented as means of individual means [min; max]. Except for first line, each unit is arbitrary units. RPE, rate of perceived exertion; sRPE, session-rate of perceived exertion; ACWR, Acute:Chronic-Workload Ratio.

The average of maximum ACWR during the 10-week period was 2.52 (range = 1.61 to 4.02) demonstrating that every athlete had at least 1 day with ACWR above 1.5 during the study period (i.e. last 7 days TL was 50% higher than average TL during previous 28 days). However, we identified different patterns of training load, including some consistent with risk of fatigue or injury, across participants. Representative examples are shown in *Figures 2A and 2B.* Athlete A took 2 weeks off of training and then demonstrated a marked increase in ACWR after 1 week of return to participation with a value exceeding 1.5, a pattern

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consistent with overloading and increased injury risk [13]. The week after his ACWR peak, we observed a decrease in a vagally-related HRV variable (supine RMSSD), which may be related to transitional fatigue. Athlete B took a shorter training break and implemented rest days during training resumption resulting in a more modest increase in ACWR. Supine RMSSD of this athlete decrease during the peak and was back to a priori baseline values 1 week after the peak.

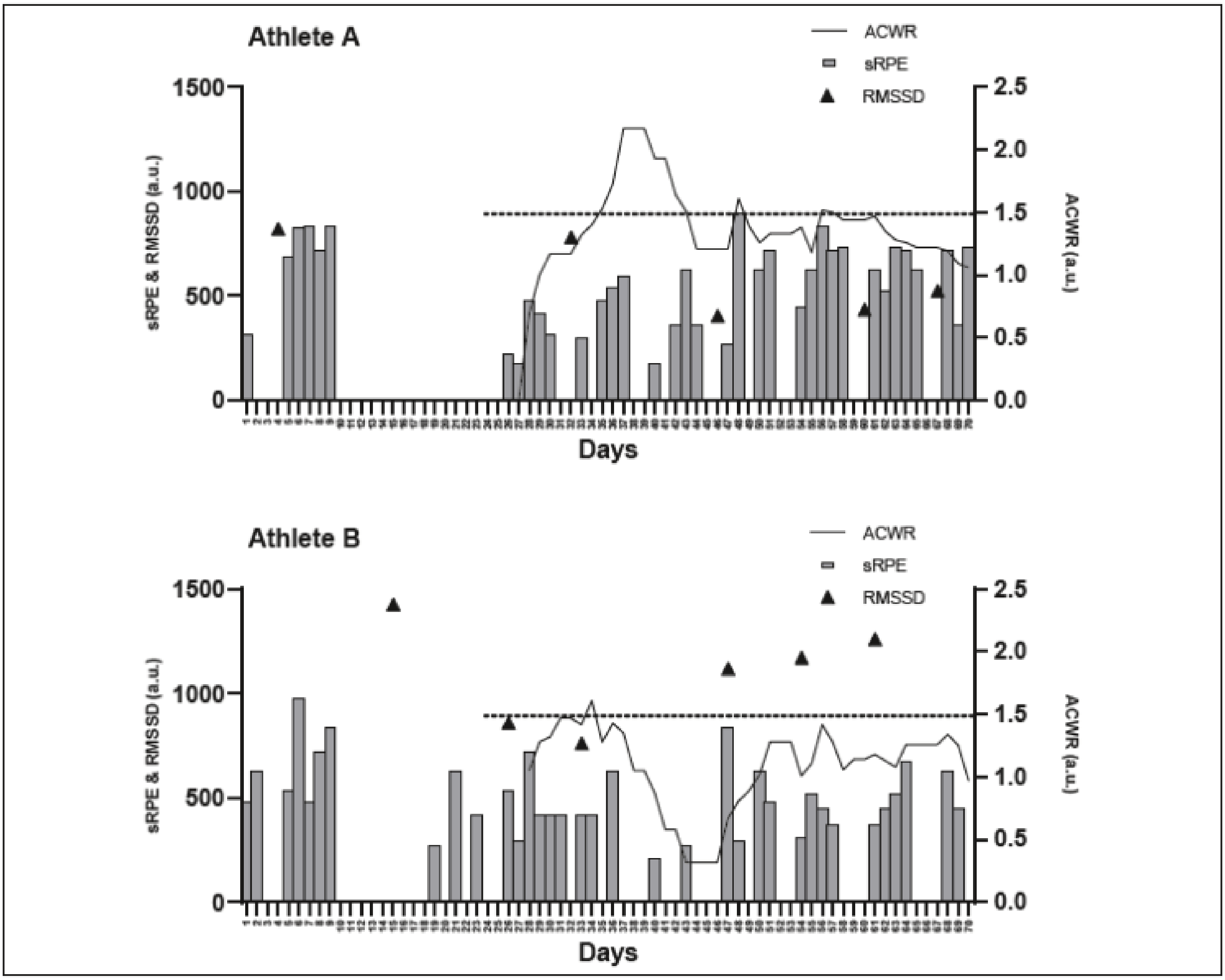

Figure 2A and 2B: Evolution of sRPE, ACWR and supine RMSSD of two athletes. sRPE, session rate of perceived exertion. ACWR, Acute: Chronic-Workload Ratio. RMSSD, root mean square of successive differences. RMSSD values have been multiplied by 100. A.u., arbitrary units.

Heart rate variability

Two athletes did not perform any HRV measurements. Median data recorded by the remaining 8 athletes (range of 3 to 7 measures performed for each) are shown in *Table 3*. One athlete demonstrated reduced vagal tone in the supine position (HR: 73.3 (69-74) bpm, RMSSD: 25.7 (25.2-37.7) ms, HF/HR: 5.8 (5.4-11.4)) but did not report any corollary symptoms nor performance decrement.

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	Supine	Standing
HR (bpm)	60.3 (57.9; 64.2)	94 (92; 97.2)
RMSSD (ms)	98.2 (63.4; 110.9)	17.5 (12.6; 22.9)
VLF (ms²)	1946.6 (941.5; 3872.7)	923.7 (743.4; 1322.6)
LF (ms²)	1888 (1429.3; 2239.6)	1213.5 (788.5; 2139.4)
HF (ms²)	3166.8 (1586.3; 4007.5)	107.9 (93.7; 197.9)
HF/HR	40.8 (27.6; 68.4)	
LF/HR		12.7 (8; 24.2)
LF/HF	0.61 (0.48; 0.86)	11.4 (8.85; 12.51)
LF+HF (ms²)	5306.1 (4066.1; 5836)	1292.6 (849.8; 2297.9)
(LF+HF)/HR	76.3 (66.4; 103.5)	
TP (ms²)	8448.6 (5703.7; 10273)	2437.2 (1708.3; 3506.9)
LFnu	37.4 (31.8; 46)	91.9 (89.1; 92.6)
HFnu	62.6 (54; 68.2)	8.1 (7.4; 10.9)

Table 3: Time- and frequency-domain HRV analysis. *Caption:* Data are medians of medians with 25th-75th percentiles. HR, heart rate; RMSSD, root-mean square of successive difference; VLF, very low frequencies; LF, low frequencies; HF, high frequencies; HF/HR, high frequencies relative to heart rate; LF/HR, low frequencies relative to heart rate; LF/HF, ratio LF in function of HF; LF+HF, addition of low and high frequencies; (LF+HF)/HR, addition of low and high frequencies relative to heart rate; TP, total power. nu, normalized unit

Adherence-satisfaction

Training log
Before intervention, no training diary was filled by athletes. Coaches asked daily via short text messages (eg. Whatsapp) for subjective feedbacks to have a successful rate. They reported difficulties like several demands or time loss having recurrent feedbacks from some athletes. When compiling every available days with available data, training logs were completed at a 98 ± 5% rate (eg. 64 days filled out of 70 = 92% rate).

Heart rate variability
Seven of 10 participants did at least 5 measurements (7.1 ± 2.4 measurements) including one participant who reached the goal of performing all weekly measurements during the 10-week study period. HRV data in from this group coupled with the prevalence of data removed from final analyses are shown in *Table 4*. Two participants performed no measurements during the study period. When queried about non-compliance, one participant answered that he forgot and the other provided no justification.

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	Absolute	Relative
Number of measures (n = 10)	5.7 ± 3.7 [0; 10]	57 ± 36.5% [0; 100]
Number of measures (n = 8)*	7.1 ± 2.4 [3; 10]	71.3 ± 23.6% [30; 100]
Supine		
Excluded because of realization issue/context	2.0 ± 1.8 [0; 5]	25.2 ± 20.5% [0; 50]
Excluded because of artifacted signal	0.5 ± 0.9 [0; 2]	5.9 ± 11% [0; 25]
Accepted measurements for interpretation	4.9 ± 1.5 [3; 7]	48.8 ± 14.6% [30; 70]
Standing		
Excluded because of realization issue/context	1.6 ± 1.6 [0; 4]	34.2 ± 31.1% [0; 80]
Excluded because of artifacted signal	0.3 ± 0.5 [0; 1]	2.6 ± 4.9% [0; 11.1]
Accepted measurements for interpretation	5.3 ± 1.8 [3; 8]	76.4 ± 19.2% [50; 100]

Table 4: Descriptive statistics of HRV measurements available. *Caption:* *Supine and standing details present data only for athletes who did measurements (2 athletes had no measurements)

HRV experience survey
Subjective post-study feedback regarding HRV was successfully solicited from 9 out of 10 participants. On a scale from 1 (not constraining) to 10 (extremely constraining), athletes (n=9) rated 3.3 ± 1.9 [0;6] performing the HRV measurements. When queried about the primary impediment to HRV compliance, 4 out of 9 reported having their wake up time moved 10 minutes earlier, 2 out of 9 indicating that HRV testing took too much time, 1 out of nine found testing to be “boring”, and 3 out of 9 provided no explanation. In response to the question: “would you agree doing more than one measurement per week?”, 7 out of 9 athletes indicated they would comply this request. Of these 7, 6 participants reported that 2 measurements per week would be acceptable and 1 participant indicated he/she would agree to daily testing. Among the 2 participants that indicated that they would not comply this request, one cited the earlier wake up time as the primary justification and the other provided no answer. When questioned about suggestions for improvement of the HRV protocol, responses focused on reducing measurement time duration and less emphasis on the need to stay calm and focus on quiet breathing.

Discussion

This study describes a 10-week evaluation of training load in young judokas and depicts normative HRV values for this population. Our data highlight the challenges with compliance to HRV monitoring among young competitive athletes, and provides perspectives for future improvement.
Alongside other conventional indices of “well-being”, sRPE has been shown to be a key variables of interest in young judokas [19]. While it has been criticized from statistical point of view [20], ACWR is easy to calculate and may be a useful indicator for of over-training, especially when it reaches or exceeds values of 2.0 [21]. Our data, of particular interest to coaches, demonstrate a pattern of ACWR values exceeding 2.0 during the first week of training resumption after breaks for holidays and/or planned periods of active rest. This period of time therefore appears to be associated with a high risk of acute overtraining. At the extreme, one athlete in our cohort who was injured prior to a holiday break experienced ACWR values in excess of 4.0 during his initial return to organized training. In contrast, some athlete with interpretable HRV measurements experienced a decrease in HRV when TL was increased in a reasonable way (ACWR ~1.5, eg. Figure 2B), questioning about the fatigability of this particular athlete. Further research will be

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required to better delineate the relationships between TL and HRV modulation and eventually suitability of HRV monitoring as a replacement for training logs.
Very few studies exist on supine short-term HRV references values in young athletes. Our results are in line with the study of Sharma et al. which examined 79 young athletes aged 12-17 years (athlete: a student who had represented the school at state, national or international level athletic interscholastic sport event) [22]. Boys (n=49) showed a median HR of 72.3 bpm and a RMSSD of 100.3 ms. HF was 2219 ms2 [22]. It is known that HRV declines with age [23] and is elevated in youth. However, Sharma study reports median RMSSD in non-athletic boys being 58.70 ms with HF of 988 ms2. When compared to a group of 40 older healthy and active participants (30.6 ± 3.1 yo – *unpublished data,* (RMSSD: 51.3 (31.9-79.2) ms, HF : 793.6 (344.8-1658.9) ms^2) Data as median *(25th quartile-75th quartile))*, judokas results were significantly higher. Another study by Toufan and al. compared 50 professional athletes to 50 non-athletes while separating static (eg. Weightlifting) to dynamic sports (Eg. soccer) in athletes (average age: 26.5 yo). No difference in HRV indexes except for HR was observed. RMSSD for static and dynamic group were 59.2 ± 37.5 and 65.8 ± 40.5 ms, respectively [24]. Judo was not studied but implying high-intensity intermittent actions, it can be qualified as dynamic sport [25]. Lower heart rate and corollary increases in beat-to-beat variability [26] in response to exercise accompanies morphological and electrical cardiac remodeling in a sport specific fashion [27,28]. While it is has been shown that regular aerobic training typically improves HRV [29], data examining HRV across sporting disciplines and in varied age groups, including those characterized by primarily isometric training, are lacking [30,31]. Future research will be required to further refine our understanding of HRV across and within sports.
Despite clear relevance and marked simplicity of collecting sRPE [7], alongside with a thorough explanation and an online collection tool, athletes in this study failed to consistently complete training logs during the initial phase In response to this observation, coaches elected to play a more “hands-on” role to improve participant compliance. Specifically, coaches directed each participant to send their activity/duration and RPE to a single dedicated coach who in turn entered participant data into the electronic record. This lead to near universal compliance but came the cost of increased time and energy expended by a coach. In contrast, adherence to the acquisition of high quality HRV measurements, despite measures including thorough participant training, was accompanied by less optimal compliance. Possible explanation relate to the currently available HRV monitoring technology include the length of time required for data acquisition and the need for serial measurements to accurately capture trends related to training load.
The ultimate intended purpose of HRV monitoring among athletes is to measure how athletes react to training load in real time, thereby providing opportunities make changes in response to either over or under-training trends. While this study was not designed to address the efficacy of this strategy, our data provide insights into the challenges of this approach and provide tangible directions for future work. Refinement in HRV technology that permits more rapid acquisition of data will prove useful. Accurate TL monitoring continues to be a challenge, especially with respect to providing results in a meaningful manner to athletes and coaches with more effective data analysis and interpretations [11]. Accordingly, automated systems that integrate HRV data with other metrics of TL or recovery (eg. sleep evaluations) coupled with platforms that deliver results in an easily digestible manner (eg. https://athlyts.com/) are warranted.
We acknowledge several limitations of this descriptive study examining real-life TL monitoring. First, our

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limited sample size precludes definitive determination of normative HRV data among young judokas. Larger data sets powered to address this as a primary outcome are warranted. Second, we collected data on sRPE which is by definition, a subjective metric that is subject to bias associated self-interpretation and unmeasured environmental factors. Nonetheless, sRPE represents one of the most common tools to assess training load and thereby justifying our use of this potentially imprecise variable. Future investigation focusing young athlete's knowledge about TL and corollary fatigue may bring key information to future advances in technology and application (eg. gamification).

Practical implications

– sRPE is a relevant tool for coaches of young judokas training in various structures as it brings objective metrics on fatigue and training monitoring. However, despite implementing a simple solution, consistent data reporting still demands time and energy. Excellent compliance was possible when coaches were involved in the process of data acquisition and recording.
– Preliminary data defining HRV among young judokas who train regularly (~4 sessions/week) are similar to those reported among well trained, older high level athletes.
– HRV monitoring compliance was suboptimal among young judokas and opportunities for future improvement are suggested by our data.

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Supplementary material

Excel sRPE sheet is available by contacting the corresponding author.

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