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# Ultrashort Versus Criterion Heart Rate Variability Among International-Level Girls' Field Hockey Players

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***Purpose:*** To assess heart rate (HR) variability responses to various markers of training load, quantify associations between HR variability and fitness, and compare responses and associations between 1-minute ultrashort and 5-minute criterion measures among a girls' field hockey team. ***Methods:*** A total of 11 players (16.8 [1.1] y) recorded the logarithm of the root mean square of successive differences (LnRMSSD) daily throughout a 4-week training camp. The weekly mean ($LnRMSSD_M$) and coefficient of variation ($LnRMSSD_{CV}$) were analyzed. The internal training load (ITL) and external training load (ETL) were acquired with session HR and accelerometry, respectively. Speed, agility, repeated sprint ability, and intermittent fitness were assessed precamp and postcamp. ***Results:*** Similar increases in the ultrashort and criterion $LnRMSSD_M$ were observed in week 3 versus week 1 ($P < .05$–.06, effect size [ES] = 0.28 to 0.36). The ultrashort and criterion $LnRMSSD_{CV}$ showed small ES reductions in week 2 (ES = –0.40 to –0.50), moderate reductions in week 3 (ES = –0.61 to –0.72), and small reductions in week 4 (ES = –0.42 to –0.51) versus week 1 ($P > .05$). Strong agreement was observed between the ultrashort and criterion values (intraclass correlation coefficient = .979). The ITL:ETL ratio peaked in week 1 ($P < .05$ vs weeks 2–4), displaying a weekly pattern similar to $LnRMSSD_{CV}$, and inversely similar to $LnRMSSD_M$. Changes in the ultrashort and criterion $LnRMSSD_{CV}$ from week 1 to 4 were associated with ITL ($P < .01$). The ultrashort and criterion $LnRMSSD_{CV}$ in week 4 were associated ($P < .05$) with postcamp fitness. ***Conclusions:*** The ultrashort HR variability parameters paralleled the criterion responses, and the associations with ITL and fitness were similar in magnitude.

***Keywords:*** autonomic, parasympathetic, sports science, youth, adaptation

Team-sports training imposes technical–tactical, cardiorespiratory, and neuromuscular demands on athletes to stimulate adaptations that enhance physical performance. Despite following standardized programming, players within a team often exhibit considerable heterogeneity in their adaptation to training.[1] Thus, tracking individual responses allows coaches to identify players exhibiting decrements in recovery status and intervene with appropriate program modifications. A practical, low-cost, and noninvasive biomarker that coaches can use to monitor athletes is resting heart rate (HR) variability (HRV).[2] A variety of linear, nonlinear, and frequency-based HRV parameters can be used to infer varying aspects of cardiac-autonomic functioning. For practical purposes, utilization of a single index reflective of parasympathetic modulation would simplify analyses for coaches. Accordingly, the natural logarithm of the root mean square of the successive differences (LnRMSSD) has gained traction as the preferred vagal-related HRV parameter in field settings for reasons described previously.[2]

Methodological comparisons have demonstrated superiority of the weekly mean ($LnRMSSD_M$) relative to isolated LnRMSSD recordings for assessing training responses in endurance athletes[3] and have been implemented with sports teams. When interpreted in conjunction with $LnRMSSD_M$, the magnitude of daily LnRMSSD fluctuations (represented by the coefficient of variation [$LnRMSSD_{CV}$]) aid in assessing training adaptations.[4,5] For example, improvements in aerobic fitness following training have been associated with increased or stable $LnRMSSD_M$ and reduced $LnRMSSD_{CV}$.[6,7] In addition, LnRMSSD parameters have been shown to reflect adaptation to variations in internal (ITL) and external (ETL) training loads. Exposure to intensified or novel training reduces $LnRMSSD_M$ and increases $LnRMSSD_{CV}$,[4,8] while improvements in or a reversion of these markers to the baseline reflect adaptation to the workload stimulus.[6,7,9]

Although studies have shown that vagal-related HRV parameters are sensitive indicators of status in adolescent boys' sports teams,[10] investigations involving high-level adolescent girls are limited. This research is warranted because HRV parameters evolve from childhood to adulthood and are affected by physical activity, sports training, and body composition characteristics.[11] Moreover, sex-related differences in HRV could potentially result in differential effects of training on autonomic function. For example, high school–aged female endurance athletes display significantly higher vagal-related HRV than male teammates, despite exposure to the same longitudinal training regime.[11] However, this study involved only the preseason and postseason assessment of HRV.[11] The characterization of week-to-week changes is needed to facilitate player monitoring throughout training.

The criterion recommendation for HRV acquisition procedures involves a 5-minute RR interval recording.[12] These lengthy procedures can limit longitudinal tracking due to low compliance from athletes.[13] Thus, a shorter methodology involving ultrashort (60 s) recordings[14] preceded by a 60-second stabilization period[15,16] has been recommended. These shortened procedures show acceptable agreement with criterion methodology.[9] However, comparisons of ultrashort versus criterion measures are largely limited to a single time point or preintervention and postintervention assessment. Moreover, the comparisons are limited to assessing the agreement

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between measures, failing to address associations and responses with workloads and performance. From a practical standpoint, coaches are more concerned about whether ultrashort parameters are sensitive to training and performance outcomes. Therefore, a more rigorous investigation comparing daily ultrashort and criterion recordings throughout a longitudinal training program with consideration of workloads and performance is required.

It is currently unknown whether LnRMSSD parameters are sensitive to training load (TL) or are associated with performance markers among adolescent female athletes. In addition, whether ultrashort measures are appropriate for daily monitoring among this population has yet to be investigated. To address these gaps in the research, we aimed to (1) assess the LnRMSSD responses to various markers of TL, (2) quantify the associations between the LnRMSSD and performance parameters, and (3) determine if the responses and associations differed between the ultrashort and criterion measures among adolescent girls' field hockey players.

# Methodology

## Study Design

This observational study used a within-subjects repeated-measures design to compare the effects of a variety of TL markers on ultrashort and criterion LnRMSSD parameters among high-level adolescent girls' field hockey players. Associations between performance markers, training load, and LnRMSSD parameters were quantified precamp and postcamp.

## Subjects

A total of 11 members (age = 16.8 [1.1] y; height = 157.1 [5.2] cm; weight = 55.2 [5.2] kg) from the Mexican field hockey national team (experience level = 5.8 [1.7] y) volunteered for this study. All players were cleared by the team physician to participate in intense physical exercise without restriction. All players and their parents were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed assent and consent document, respectively, to participate in the study. The study protocol followed the guidelines expressed by the Declaration of Helsinki and was approved by UANL's (*Universidad Autónoma de Nuevo León*) Health Sciences Research Bioethics Committee (No.: COBICIS-58/12/2017/02-FOD-BRRC).

## Procedures

***Training Camp.*** The observation period involved a 4-week training camp that occurred in July of 2018, preceding the Youth Olympic Games in Buenos Aires, Argentina. The training sessions were conducted by the coaching staff and were uninfluenced by the researchers. All subjects performed the same strength and conditioning training. The technical–tactical drills differed only for the goalies (n = 2). The weekly training schedule was maintained the first 3 weeks of training camp and is described in Table 1. During week 4, the afternoon sessions were replaced with competitive scrimmages.

***Performance Tests.*** Performance tests were conducted at 6:30 AM in a fasted state before and after camp, with a minimum of 24-hour rest from previous training. The players performed a light warm-up, including jogging and dynamic stretches for the upper and lower body, prior to testing. The performance tests were implemented on a water-based hockey pitch in the following order: 40-m sprint test, Illinois agility test, 6 × 30-m repeat sprint ability (RSA) test, and the intermittent fitness test (IFT 30–15). The agility, sprinting, and RSA test times were measured with an electronic timing system (Brower Timing Systems, Draper, UT). The agility and sprint tests were performed twice, and the best time was recorded for analysis. All of the procedures were familiar to the athletes.

***Fat Mass.*** Anthropometric measures were acquired before breakfast on the day following the performance tests at precamp and postcamp. All measures were performed by the primary investigator for consistency. Height was measured with a digital stadiometer (Model 274; Seca GmbH, Hamburg, Germany). Weight was

**Table 1 Weekly Training Camp Structure Throughout Weeks 1 to 3**

| Session | Hour | Mon | Tue | Wed | Thu | Fri | Sat | Sun |
|---|---|---|---|---|---|---|---|---|
| | 6:30–7:00 | HRV | HRV | HRV | HRV | HRV | HRV | HRV |
| Morning | 7:00–7:30 | Sprint | Plyometric | Agility | Sprint | Plyometric | Rest | Rest |
| | 7:30–9:00 | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Rest |
| | 9:00–10:00 | Breakfast | Breakfast | Breakfast | Breakfast | Breakfast | Breakfast | Breakfast |
| | 10:00–13:30 | Rest | Rest | Rest | Rest | Rest | Rest | Rest |
| Midday | 13:30–15–30 | Resistance | Rest | Resistance | Rest | Resistance | Rest | Rest |
| | 15:30–16:30 | Lunch | Lunch | Lunch | Lunch | Lunch | Lunch | Lunch |
| | 16:30–18:30 | Rest | Rest | Rest | Rest | Rest | Rest | Rest |
| Afternoon | 18:30–20:00 | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Technical–tactical | Rest |
| | 20:00–20:30 | Conditioning | Core strength | Rest | Conditioning | Core strength | Rest | Rest |

Abbreviation: HRV, heart rate variability. Note: In week 4, competitive scrimmages replaced afternoon sessions. One technical–tactical session was performed on Sunday morning of week 1 only. Resistance sessions involved multijoint and single-joint exercises for all major muscles, using barbells, dumbbells, and cable pulleys. Movements were performed for 3 sets, with repetitions progressively decreasing throughout weeks from 15 to 3, while intensity progressively increased from 60% to 90% of 1-repetition maximum, with a 2- to 3-minute interset rest. Core strengthening involved leg raise variations, crunches, and planks performed for 2 to 3 sets of 8 to 20 repetitions with a 2-minute interset rest. Conditioning sessions progressed from 4 to 6 sets of 440-m to 10 to 12 sets of 220-m sprints with rest periods decreasing from 2.5 to 2 minutes. Plyometric sessions involved various hops, skips, bounds, and jumps performed for 2 sets of 5 to 10 repetitions with a 2-minute interset rest. Agility sessions involved 5 different drills (ladders, cones, and reactive change of direction) performed for 2 repetitions with a 2-minute interset rest.

measured with a medical digital scale (Model TBF_310; Tanita Corporation, Tokyo, Japan). Skinfold thickness (Slim Guide caliper; Creative Health Products, Ann Arbor, MI) was measured at the triceps brachii, subscapular, supraspinale, abdominal, anterior thigh, and medial gastroc sites on players' right side for body density analysis using the Wither equation for female athletes.[17] Relative fat mass was calculated using the Siri equation.[18]

***Training Load.*** During training sessions, the HR data were collected at a 1-Hz sample rate (Team2; Polar Electro Oy, Kempele, Finland) and later exported to a personal computer for analysis. ITL was then calculated with a modified training impulse (TRIMP) method[19] as the sum of every HR value of the training session converted to HR reserve, multiplied by time in minutes, and weighted using a fixed exponential factor representing changes in HR and blood lactate concentration for incremental exercise in women.[20] The formula was as follows:

$$\text{TRIMP} = \sum \text{HR}_{\text{res}} \times t \times (0.86 \times e^{1.67 \times \text{HR}_{\text{res}}}),$$

where $\text{HR}_{\text{res}}$ = heart rate reserve, $t$ = time, and e = Napierian logarithm of 2.712.

The modified TRIMP was selected because, rather than using the session's average $\text{HR}_{\text{res}}$, it considers each HR value of the training session, more accurately reflecting its intermittent nature.

The ETL was determined using triaxial accelerometers (ActiGraph LLC, Pensacola, FL) attached to the HR monitor chest strap. This position places the accelerometer near the subjects' center of mass, which better represents whole body movements. Accelerometer TL is considered a practical approach to monitor ETL in team sports. Each accelerometer had a full-scale output range of ±6 *g* and sampled at a rate of 100 Hz. Whole-body movements were determined as the accumulated instantaneous rate of change in acceleration in the 3 movement planes. ETL was then calculated via ActiLife software (2016, version 6.13.3; ActiGraph LLC, Pensacola, FL) using Player Load methodology[21] with the following formula:

$$\text{Player Load} = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}},$$

where $a_y$ = anteroposterior acceleration, $a_x$ = mediolateral acceleration, and $a_z$ = craniocaudal acceleration.

The integration of ITL and ETL as a ratio provides novel insight regarding the physiological load relative to the imposed external load and can be used to infer training adaptation.[22] The ITL:ETL ratio was calculated using the following formula:

$$\text{Ratio} = \frac{\text{ITL}}{\text{ETL}}.$$

***HRV Recordings.*** Postwaking HRV was measured daily throughout the training camp at 6:00 AM in the players' dormitory. The RR intervals were collected using a chest-strap transmitter (H7; Polar Electro Oy), which was connected by Bluetooth to the Elite HRV Smartphone application (Elite HRV, Ashville, NC). The players were instructed to moisten and fit the chest strap around their chest and perform a seated HRV measure while remaining quiet and motionless, and breathing spontaneously. After a 1-minute stabilization period, a 5-minute HRV recording was initiated. The raw RR data were later exported to a computer for analysis with Kubios HRV Premium software (version 3.0.2; Kubios, University of Kuopio, Kuopio, Finland).[23] The data were visually inspected, and any ectopic beats or artifacts were eliminated using the built-in "automatic correction" filter function of the Kubios software. LnRMSSD was derived from the first minute (ie, ultrashort) and the full 5-minute (ie, criterion) segment for evaluation. The $\text{LnRMSSD}_{\text{M}}$ and $\text{LnRMSSD}_{\text{CV}}$ values were calculated intraindividually for each week. $\text{LnRMSSD}_{\text{CV}}$ was calculated as ([SD/mean] × 100).

## Statistical Analyses

The data are presented as mean (SD). Parametric tests were used when normality was confirmed with a Shapiro–Wilk test. Linear mixed models using time (ie, week) as a within-subjects repeated fixed effect and subject identification as a random effect were used to assess variation in the LnRMSSD parameters, Player Load, TRIMP, and the ITL:ETL ratio. Inclusion of the ultrashort and criterion LnRMSSD parameters within the same model would violate the assumption of independence, necessitating separate models. The intraclass correlation coefficient (ICC) was used to determine the agreement between the ultrashort and criterion LnRMSSD at the group level. Associations between daily ultrashort and criterion LnRMSSD at the individual level were quantified with Pearson *r*. Associations between $\text{LnRMSSD}_{\text{M}}$, $\text{LnRMSSD}_{\text{CV}}$, performance markers, and TL were also quantified with Pearson *r*. The correlation coefficients were interpreted qualitatively, as follows: <.3 = small, <.5 = moderate, <.7 = large, <.9 = very large, and <1.0 = near perfect.[24] Paired *t* tests were used to compare the precamp and postcamp performance values. Effect sizes were used to determine standardized differences between variables using Hedges' G. The ESs were interpreted as follows: <0.20 = trivial, <0.60 = small, <1.20 = moderate, and <2.0 = large.[24] Statistical significance was set at $P < .05$. Statistical procedures were performed using SPSS (version 23; IBM Corp, Armonk, NY).

# Results

Significant model effects were observed for the ultrashort ($P = .009$) and criterion $\text{LnRMSSD}_{\text{M}}$ ($P = .03$). The ultrashort $\text{LnRMSSD}_{\text{M}}$ increased in week 3 relative to week 1 ($P < .05$, ES = 0.36). Despite a significant model effect, post hoc analyses revealed no changes across time for the $\text{LnRMSSD}_{\text{M}}$ criterion (week 3 vs week 1, $P = .06$, ES = 0.28). No significant model effects were observed for $\text{LnRMSSD}_{\text{CV}}$ ($P > .05$). However, the ultrashort and criterion $\text{LnRMSSD}_{\text{CV}}$ showed small ES reductions in week 2 (ultrashort, criterion: ES = −0.40 to −0.50), moderate reductions in week 3 (ES = −0.61 to −0.72), and small reductions in week 4 (ES = −0.42 to −0.51) relative to week 1. The LnRMSSD values are displayed in Figure 1. An example profile of the LnRMSSD and ITL:ETL ratio data from a single player can be viewed in Figure 2.

Significant model effects were observed for Player Load, TRIMP, and the ITL:ETL ratio (all *P*s < .01). Player Load in week 2 and 3 was greater than in weeks 1 and 4 ($P < .05$, ES = 0.91 to 1.07). TRIMP in week 4 was lower than in all other weeks ($P < .05$, ES = −0.70 to −1.11). The ITL:ETL ratio in week 1 was greater than in all other weeks ($P < .05$, ES = 0.64 to 1.08). The TL values are displayed in Figure 1.

The ICC between the ultrashort and criterion measures was near perfect (ICC [95% CI] = .979 [.972–.985], $P < .001$). Within-subject associations between the ultrashort and criterion LnRMSSD ranged from very large to near perfect and are presented in Table 2.

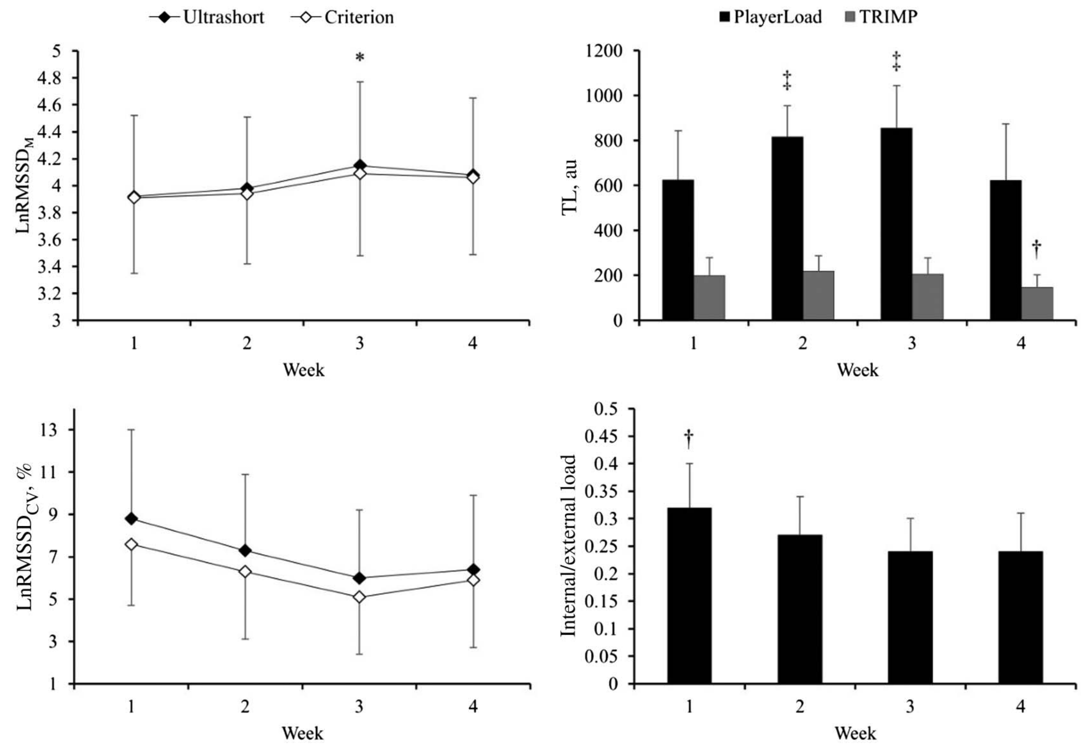


**Figure 1** — Mean and SD for the weekly average (LnRMSSD$_M$) and coefficient of variation (LnRMSSD$_{CV}$) for the natural logarithm of the root mean square of successive differences, Player Load, TRIMP, and internal/external TL ratio. LnRMSSD indicates logarithm of the root mean square of successive differences; TL, training load; TRIMP, training impulse. *Different from week 1 for ultrashort LnRMSSD$_M$ ($P < .05$). ‡Different from weeks 1 and 4 ($P < .05$). †Different from all other weeks ($P < .05$).

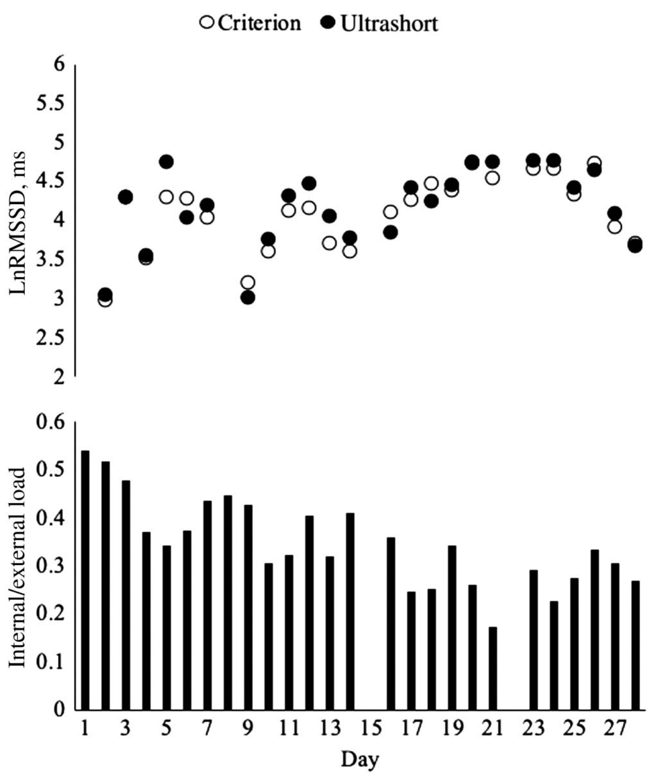


**Figure 2** — Example of an individual athlete daily LnRMSSD and internal/external TL ratio profiles. LnRMSSD indicates logarithm of the root mean square of successive differences; TL, training load.

**Table 2 Within-Subject Associations Between Ultrashort and Criterion Recordings**

| Player | n | *r* | *P* |
|---|---|---|---|
| 1 | 23 | .91 | <.0001 |
| 2 | 22 | .84 | <.0001 |
| 3 | 24 | .86 | <.0001 |
| 4 | 24 | .93 | <.0001 |
| 5 | 22 | .82 | <.0001 |
| 6 | 24 | .89 | <.0001 |
| 7 | 23 | .92 | <.0001 |
| 8 | 22 | .96 | <.0001 |
| 9 | 23 | .94 | <.0001 |
| 10 | 21 | .87 | <.0001 |
| 11 | 23 | .87 | <.0001 |
| Group | 251 | .96 | <.0001 |

Significant improvements in relative fat mass were observed from precamp to postcamp ($P < .05$). IFT 30–15 improved at postcamp ($P < .05$). The 40-m sprint times were slower at postcamp ($P < .05$). The fat mass and performance values are presented in Table 3.

There were no significant associations between the precamp performance measures and week 1 LnRMSSD parameters (all *P*s > .05). At postcamp, the week 4 ultrashort and criterion LnRMSSD$_{CV}$ were similarly and significantly (all *P*s < .05) associated with IFT 30–15 (ultrashort vs criterion, $r = -.71$ vs $r = -.78$),

**Table 3 Mean and SD for Precamp and Postcamp Fat Mass and Performance Parameters**

| Performance parameter | Pre | Post | Difference | *P* | Effect size |
|---|---|---|---|---|---|
| Fat mass, % | 21.4 (2.6) | 19.6 (2.0) | −1.83 | .003 | −0.87 |
| Agility, s | 19.5 (0.88) | 19.4 (1.10) | −0.10 | .575 | −0.10 |
| 40-m sprint, s | 6.42 (0.37) | 6.57 (0.45) | 0.15 | .028 | 0.35 |
| IFT 30–15, km/h | 16.77 (1.42) | 17.64 (1.51) | 0.86 | .012 | 0.57 |
| RSA, s | 31.75 (1.86) | 31.45 (2.26) | −0.30 | .213 | −0.14 |

Abbreviations: IFT, intermittent fitness test; RSA, repeat sprint ability.

agility ($r = .77$ vs $r = .85$), 40-m sprint ($r = .76$ vs $r = .66$), and RSA ($r = .76$ vs $r = .81$). The scatter plots are presented in Figure 3. No significant associations were observed for $\text{LnRMSSD}_M$ (all $P$s > .05).

The changes in the ultrashort and criterion $\text{LnRMSSD}_{CV}$ from week 1 to week 4 were significantly associated with the mean ITL ($r = -.77$, $P = .005$ vs $r = -.84$, $P = .001$). No significant associations were observed for $\text{LnRMSSD}_M$ (all $P$s > .05).

## Discussion

The aims of this study were to assess the LnRMSSD responses to ITL and ETL, quantify the associations between the LnRMSSD and performance parameters, and determine if the LnRMSSD responses and associations differed between the ultrashort and criterion measures among girls' field hockey players. The main findings were (1) the LnRMSSD responses to training were consistent with the responses observed among adult sports teams, (2) the changes in $\text{LnRMSSD}_{CV}$ from week 1 to week 4 were associated with the mean ITL, (3) the $\text{LnRMSSD}_{CV}$ in week 4 was significantly associated with the postcamp performance markers, and (4) similar TL responses and performance associations were observed between the ultrashort and criterion LnRMSSD parameters.

The weekly ITL:ETL ratio shared a similar weekly pattern with $\text{LnRMSSD}_{CV}$, and inversely so with $\text{LnRMSSD}_M$ (Figure 1). As ETL increased, ITL remained stable, indicating that the physiological load lessened throughout camp, as did its impact on autonomic function (ie, LnRMSSD parameters). In agreement with these findings, previous investigations have reported reduced or stable $\text{LnRMSSD}_M$ and increased $\text{LnRMSSD}_{CV}$ during the first week of a novel training stimulus, with progressive improvements thereafter, despite increments in ETL. For example, Olympic-level men's rugby sevens players showed greater $\text{LnRMSSD}_{CV}$ (ES = 0.38) during the first week of intensive training, with a subsequent reduction the following week (ES = −0.91), concurrent with increments in high-speed running distance (ES = 1.11).[7] Similarly, Nakamura et al[25] reported progressive improvements in LnRMSSD parameters throughout a 4-week training camp in elite men's futsal players, despite increments in perceived TL (week 1 vs week 4. $\text{LnRMSSD}_M$ ES = 0.59, $\text{LnRMSSD}_{CV}$ ES = −0.81). However, in the current study, $\text{LnRMSSD}_M$ and $\text{LnRMSSD}_{CV}$ were the highest (ultrashort, criterion: ES = 0.36 to 0.28) and lowest (ES = −0.61 to −0.72), respectively, in week 3 rather than week 4. This may be due to week 4 involving competitive scrimmaging, with coaches finalizing the player selection and depth chart status for the upcoming youth Olympics. Competition has been shown to effect LnRMSSD parameters to a greater extent than typical training.[26]

A novel finding of the current investigation was that the players who performed the greatest ITL showed the greatest reductions in $\text{LnRMSSD}_{CV}$. This may be explained by the fact that the players who performed the greatest ITL also exhibited the greatest increments in fitness. To verify this interpretation, we examined the association between mean ITL and changes in RSA from precamp to postcamp, which revealed a large inverse association ($r = -.60$, $P = .05$). Thus, improvements in fitness throughout the camp likely enabled players to perform and recover from greater ITL, the latter of which may be reflected in reduced $\text{LnRMSSD}_{CV}$. This distinction is important because an alternative interpretation may be that coaches should aim to maximize ITL to stimulate improvements in fitness, which may cause increased fatigue and decrements in LnRMSSD parameters.[8,27] In other words, increments in ITL may only be desirable for stimulating improvements in fitness, provided that LnRMSSD parameters are reflecting positive coping responses. Thus, the current findings support the use of ITL in conjunction with additional physiological indicators of training adaptation to monitor players.

The authors observed no significant associations between the week 1 LnRMSSD parameters and precamp markers of performance. However, the week 4 $\text{LnRMSSD}_{CV}$ was significantly associated with all postcamp performance markers. These findings are in agreement with Boullosa et al,[28] who showed that $\text{LnRMSSD}_{CV}$, derived from nocturnal recordings in elite adult men's soccer players, was significantly associated with intermittent running performance ($r = -.90$, $P < .01$) only at postcamp. Other investigations in elite men's[7,25] or U-19[8] team-sport players and collegiate women's soccer players[6] found similar associations between $\text{LnRMSSD}_{CV}$ and fitness markers beyond the first week of training. Thus, introduction to novel training, such as the first week of a camp, stimulates autonomic responses that may confound associations with fitness level. To our knowledge, this is the first study to find associations between $\text{LnRMSSD}_{CV}$ and neuromuscular markers (eg, agility and sprinting speed). However, we caution readers that this association is likely due to multicollinearity among performance results, as players with the highest fitness (eg, RSA and IFT 30–15) were also the fastest sprinters and most agile at postcamp.

Multiple studies have found acceptable agreement between ultrashort and criterion LnRMSSD in various adult team-sport or endurance athletes.[9,16] Nakamura et al[29] reported ICCs > .90 and showed that changes in ultrashort and criterion LnRMSSD from before and after 8 weeks of training were strongly associated among adolescent female basketball players ($r = .82$, n = 17). More recently, Chen et al[30] found good agreement between weekly ultrashort (recording duration range 30–120 s) and criterion LnRMSSD parameters among U-20 male futsal players (n = 14). However, the current study is the first to compare ultrashort and criterion LnRMSSD responses and associations with various markers of performance and TL. We found that the ultrashort $\text{LnRMSSD}_M$ and $\text{LnRMSSD}_{CV}$ paralleled the criterion responses to the TL indices and that the observed associations with the ITL and performance parameters were similar in magnitude.

The main limitation of the current study was the small roster of players. A sample size calculation with G*Power software (version 3.1.9.4; Franz Faul, Heinrich-Heine-Universität, Düsseldorf, Germany) using an ES of 0.30, an alpha of .05, and power level of 0.80

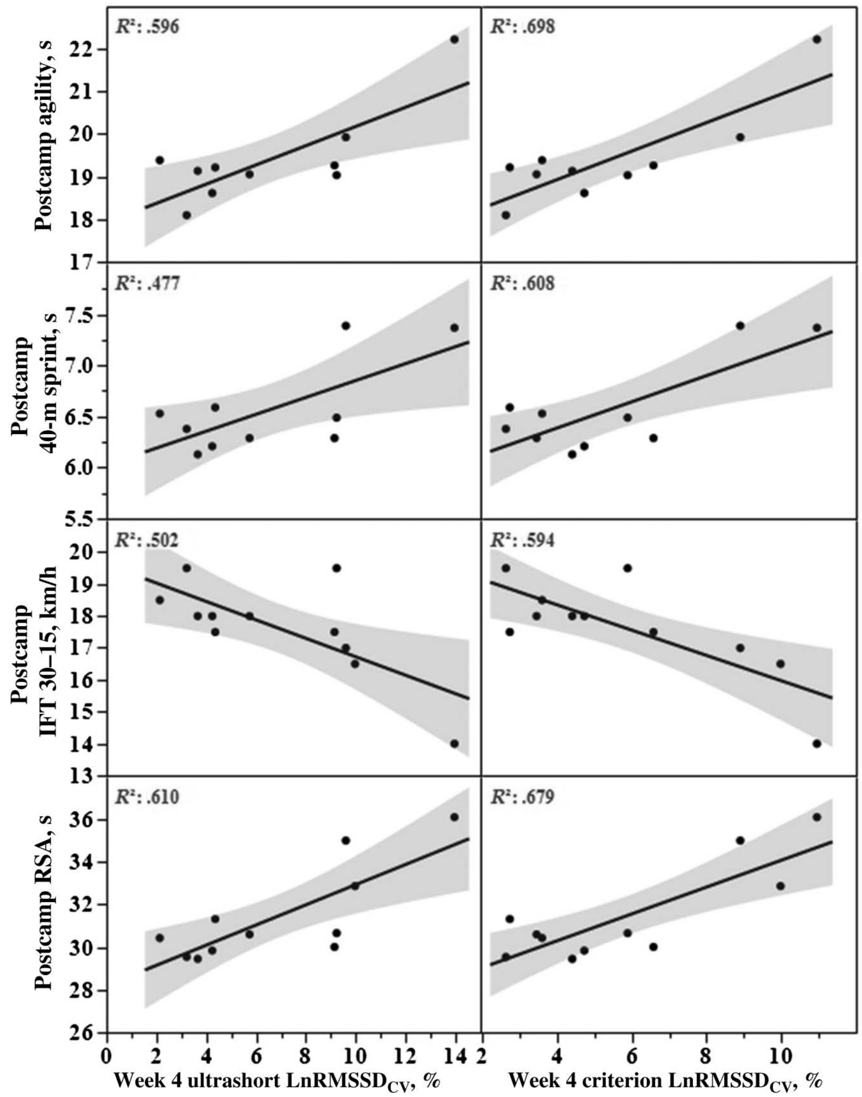


**Figure 3** — Scatter plots showing associations between week 4 coefficient of variation for the natural logarithm of the root mean square of successive differences and postcamp performance markers. IFT indicates intermittent fitness test; LnRMSSD, logarithm of the root mean square of successive differences; RSA, repeat sprint ability.

determined that 17 subjects would have been more appropriate. Other limitations include the use of a mobile application for HRV acquisition, lack of menstrual cycle tracking, and lack of a precamp (ie, baseline) assessment of the LnRMSSD parameters. Nevertheless, this study provides the most thorough investigation to date into the efficacy of the ultrashort LnRMSSD for reflecting training responses in team-sport players. Our findings suggest that ultrashort LnRMSSD responses can aid in evaluating how players are tolerating variations in workload parameters and improving fitness throughout training.

## Practical Applications

The LnRMSSD responses to training among the adolescent girls' field hockey players are comparable to the responses observed in adult athletes, regardless of sex. The peak in the ITL:ETL ratio and LnRMSSD$_{CV}$ and the lowest LnRMSSD$_{M}$ observed at the start of camp indicate that week 1 was the most physiologically taxing among players. Despite performing greater external workloads in subsequent weeks, players exhibited less relative physiological stress during and in response to training, as reflected in the reduced ITL:ETL ratio and improvements in the LnRMSSD parameters, respectively. The players exhibiting the fewest fluctuations in LnRMSSD from precamp to postcamp performed the greatest ITL and were subsequently the highest performers on the fitness tests. Thus, tracking LnRMSSD as a physiological training response marker can be useful in evaluating how players are adapting to variations in workloads. When analyzing individual trends, coaches should identify players displaying increased daily fluctuations in LnRMSSD beyond the first week of a training camp, as an elevated LnRMSSD$_{CV}$ may reflect an unfavorable response. Finally, implementing the ultrashort LnRMSSD recording procedures will yield practically the same insight regarding training adaptations as the criterion measures, in 80% less time.

## Conclusions

The current findings suggest that LnRMSSD responses may aid in evaluating how girls' field hockey players are tolerating variations in workload parameters and improving fitness throughout training.

Demanding 168 minutes of the players' time by using criterion measures throughout the 4-week camp seems unwarranted, given that similar results were obtained in only 56 minutes using the ultrashort protocol.


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