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Research article

Ultra-Short-Term Heart Rate Variability is Sensitive to Training Effects in Team Sports Players

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Abstract
The aim of this study was to test the possibility of the ultra-short-term lnRMSSD (measured in 1-min post-1-min stabilization period) to detect training induced adaptations in futsal players. Twenty-four elite futsal players underwent HRV assessments pre- and post-three or four weeks preseason training. From the 10-min HRV recording period, lnRMSSD was analyzed in the following time segments: 1) from 0-5 min (i.e., stabilization period); 2) from 0-1 min; 1-2 min; 2-3 min; 3-4 min; 4-5 min and; 3) from 5-10 min (i.e., criterion period). The lnRMSSD was almost certainly higher (100/00/00) using the magnitude-based inference in all periods at the post- moment. The correlation between changes in ultra-short-term lnRMSSD (i.e., 0-1 min; 1-2 min; 2-3 min; 3-4 min; 4-5 min) and $\mathrm{lnRMSSD_{Criterion}}$ ranged between 0.45 - 0.75, with the highest value (ρ = 0.75; 90% CI: 0.55 – 0.85) found between ultra-short-term lnRMDSSD at 1-2 min and $\mathrm{lnRMSSD_{Criterion}}$. In conclusion, lnRMSSD determined in a short period of 1-min is sensitive to training induced changes in futsal players (based on the very large correlation to the criterion measure), and can be used to track cardiac autonomic adaptations.

Key words: Court sports, athletic monitoring, cardiac autonomic system, futsal.

Introduction

Heart rate variability (HRV) is becoming one of the most used training and recovery monitoring tools in sports sciences (de Oliveira Ottone et al., 2014; Plews et al., 2013). The Task Force recommends a period of 10-min for the assessment of HRV (i.e., 5-min stabilization period and a 5-min post-stabilization measurement period). However, more recently, a shortened post-stabilization measurement period (i.e., 1-min duration) has been proposed for analyzing athletes (Esco and Flatt, 2014; Flatt and Esco, 2015a). In fact, when the natural log of the root-mean-square difference of successive normal RR intervals (lnRMSSD - a simple and practical vagally-mediated index) is measured during the standard 5-min post-stabilization period ($\mathrm{lnRMSSD_{Criterion}}$) or the shortened 1-min post-stabilization measurement period, similar values have been observed. This was demonstrated using both electrocardiogram (ECG) and portable sports cardiofrequencimeters (Flatt and Esco, 2015a). Furthermore, the Bland-Altman analysis showed tight limits of agreement between 1-min lnRMSSD and $\mathrm{lnRMSSD_{Criterion}}$ measures, while intraclass correlation coefficient (ICC) analysis have ranged between 0.84 and 0.97 (Flatt and Esco, 2015a). Therefore, the ultra-short-term HRV measurement method, demanding only 1-min of data acquisition after the stabilization period, may arguably improve the practicality of the cardiac autonomic activity monitoring on a daily basis.

The HRV indices (e.g., lnRMSSD) derived from traditional time-consuming methods have shown to be sensitive to training effects in team sports players (de Freitas et al., 2014; Oliveira et al., 2013; Soares-Caldeira et al., 2014). However, these studies used single measures per period of assessment, while recently some authors have proposed averaging multiple measures per week to increase the confidence of the data and sensitivity to detect changes related to variations in training loads (Flatt and Esco, 2015b; Plews et al., 2012; 2014). In this sense, shorter data acquisition procedures are appealing from a practical standpoint due to the difficulties in obtaining athletes' compliance to the standard 10-min procedure, and the necessity of simple monitoring tools to quantify adaptation/maladaptation to sports training.

The aim of this study was to test the possibility of ultra-short-term lnRMSSD to detect training induced adaptations. This was accomplished by comparing the changes induced by training in futsal players while using the standard and shortened HRV, before and after the preseason.

Methods

Participants

Twenty-four elite futsal players (22.9 ± 4.2 years; 1.74 ± 0.06 m; 74.4 ± 7.6 kg; 1262.0 ± 330.6 m in the Yo-Yo Intermittent Recovery Test, level 1) of two different teams, playing one of the most important state championships in Brazil (Paraná State Championship) took part in this study. The subjects of this study were directly involved in two different previous works published by our research group (Oliveira et al., 2013, Soares-Caldeira et al., 2014). The purposes of those studies were to verify the HRV and performance changes after a standard futsal preseason period. All studies were approved by the same Ethics Committee.

Procedures

All HRV assessments were conducted pre- and post-three

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or four weeks of a standard futsal preseason, before starting the most important competition of the year. The pre and post HRV measures were performed at the same hour on the bench, in the seated position, in a quiet futsal court. The athletes arrived at the futsal gym for the first training session of the week, after ≈ 48 h of rest from training sessions, in a fasted state for 2 h and free of caffeine or alcohol consumption for at least 24 h.

Prior to data collection, athletes were provided with cardiofrequencimeters and chest strap transmitters, and received verbal instructions about how to proceed. Subsequently, athletes sat down and were given <1-min to check for the functioning of the watch receiver for RR intervals acquisition. Participants received instructions to remain quiet, with eyes opened, and to breathe spontaneously (Bloomfield et al., 2001) over the acquisition period.

HRV analysis

The RR interval recordings were obtained using a portable heart rate monitor (Polar® RS800cx, Kempele, Finland) at a sampling of 1,000 Hz, continuously for 10-min[1] (Task Force, 1996, Gamelin et al., 2006, Wallen et al., 2012) . Data were visually inspected to identify artifacts and ectopic beats (<3%), which were manually removed and replaced by interpolation of adjacent RR intervals. The RR recordings were downloaded via accompanying Polar software (Polar® ProTrainer, Kempele, Finland) and exported for later analysis of time domain measures of HRV by Kubios v2 Heart Rate Variability software (Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland).

The dependent variable analyzed was the root-mean-square difference of successive normal RR intervals (RMSSD), which was transformed in lnRMSSD to avoid outliers and simplify its analysis. This variable was expressed in milliseconds. From the 10-min HRV recording period, lnRMSSD was analyzed in the following time segments: 1) from 0-5 min (i.e., stabilization period); 2) from 0-1 min; 1-2 min; 2-3 min; 3-4 min; 4-5 min and; 3) from 5-10 min (i.e., criterion period); The 1-min measures will be collectively labeled as ultra-short-term measures.

Statistical analysis

Data is presented in means and standard deviations (SD). The differences based on magnitudes (Batterham and Hopkins, 2006) were calculated to check the differences in the pre and post moments. The quantitative chances for the post- measures having higher, similar or lower values than pre- measures, using a smallest worthwhile change (SWC) of 3% (Buchheit, 2014) and a confidence internal (CI) of 90%, were assessed qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, almost certain. If the chances of having better and poorer results were both >5%, the true difference was assessed as unclear. The spreadsheet available at: http://www.sportsci.org/index-.html was used. Finally, the correlations between the ultra-short-term period of analysis (1 min) and criterion (5 min) was analysed using the Spearman's ρ test. The threshold used to qualitatively assess the correlations was based on Hopkins (2002), using the following criteria: <0.1, trivial; 0.1 - 0.3, small; 0.3 - 0.5, moderate; 0.5 - 0.7, large; 0.7 - 0.9, very large; >0.9 nearly perfect.

Results

Table 1 presents the ultra-short-term lnRMSSD and $lnRMSSD_{Criterion}$ values, both before and after preseason training. The lnRMSSD was almost certainly higher (100/00/00) in all periods at the post- moment.

The Spearman's ρ correlation between changes in ultra-short-term lnRMSSD (i.e., 0-1 min; 1-2 min; 2-3 min; 3-4 min; 4-5 min) and $lnRMSSD_{Criterion}$ ranged between 0.45 - 0.75, with the highest value (ρ = 0.75; 90% CI: 0.55 – 0.85) found between ultra-short-term lnRMDSSD at 1-2 min and $lnRMSSD_{Criterion}$.

Discussion

This study revealed that the ultra-short-term lnRMSSD was as sensitive as $lnRMSSD_{Criterion}$ to training induced adaptations in elite futsal players. The changes were rated as almost certain for all periods, demonstrating the usefulness of HRV in detecting autonomic changes taking place in the preseason.

The vagal-related indices of HRV as measured using the standard procedures of the Task Force (1996), including the stabilization period, have been shown to be responsive to training effects in both non-athletes and athletes (Da Silva et al., 2014; de Freitas et al., 2014; Oliveira et al., 2013; Plews et al., 2013; Sandercock et al., 2005; Soares-Caldeira et al., 2014). In general, a proper adaptation to the training loads leads to increased cardiac-parasympathetic activity (Da Silva et al., 2014; de Freitas et al., 2014; Kiviniemi et al., 2007; Oliveira et al., 2013; Soares-Caldeira et al., 2014), while prolonged overloading decreases this activity and inversely leads to high sympathetic modulation (Morales et al., 2014; Schmitt et al., 2013). For this reason, several research groups have

Table 1. Means (±SD†) for the ultra-short-term lnRMSSD (i.e., 0-1 min; 1-2 min; 2-3 min; 3-4 min; 4-5 min) and $lnRMSSD_{Criterion}$ values obtained before and after 3-4 weeks of preseason training in futsal players (n = 24).

	Before	After	Δ% (90% CI)	Lower/Trivial/Higher (*rating*)
0-1 min	3.3 (.6)	3.7 (.6)	12.4 (9.0 - 18.1)	00/00/100 (*almost certainly*)
1-2 min	3.1 (.8)	3.7 (.5)	17.4 (9.5 - 25.4)	00/00/100 (*almost certainly*)
2-3 min	3.2 (.7)	3.6 (.5)	11.9 (6.2 - 15.5)	00/00/100 (*almost certainly*)
3-4 min	3.2 (.7)	3.7 (.5)	15.2 (9.4 - 18.9)	00/00/100 (*almost certainly*)
4-5 min	3.2 (.6)	3.6 (.5)	13.7 (9.5 - 18.9)	00/00/100 (*almost certainly*)
Criterion (5-10 min)	3.2 (.6)	3.7 (.4)	16.1 (12.5 - 18.8)	00/00/100 (*almost certainly*)

†: values are expressed in milliseconds; Δ%: percentage of change.

been proposing constant monitoring of HRV on daily bases (Kiviniemi et al., 2007; Plews et al., 2012; 2013). However, this is impractical because coaches find it difficult to perform the standard procedure due to its long duration, making it difficult to keep the athletes quiet and thus potentially decreasing their adherence in successive daily measurements.

The ultra-short-term lnRMSSD measured after less than 60-s of stabilization was previously shown to have a high agreement with $\text{lnRMSSD}_{\text{Criterion}}$ (Esco and Flatt, 2014). This made the RR interval data acquisition more convenient and practical for daily use by coaches and athletes, although studies testing its sensitivity to training effects were still lacking. In this study, we further demonstrate the applicability of the shortened procedure to quantify lnRMSSD in team-sport players by showing that each of the 1-min windows within the stabilization period provided indices that were equally responsive to the effects of training compared to the criterion measure. This finding may help coaches and sport scientists in implementing daily (e.g., every morning after waking) assessments of HRV to guide subsequent training methods and loads and to quickly identify changes in cardiac autonomic regulation. In fact, daily HRV is labile and responsive to recent stressors - especially when averaged weekly - to reflect the effects of a given training microcycle (Flatt and Esco, 2015b, Plews et al., 2012, Plews et al., 2014). It remains to be determined if ultra-short-term HRV is sensitive to reductions of vagal influence on the heart due to overloading.

To conclude, the results reported herein reveal that lnRMSSD determined in short periods of 1-min, following only 1-min of stabilization, is sensitive to training induced changes in futsal players. This advances the practical use of this measure when monitoring athletes in field conditions.

Practical applications

Coaches and sport scientists are encouraged to use the simplified procedure of acquiring RR intervals in only 1-min, preceded by 1-min for stabilization, in the seated position at rest, to monitor vagally-mediated lnRMSSD on a daily basis due to its responsiveness to training effects. The lnRMSSD collected in a 1-min window is capable of showing meaningful alterations in the physiological state in the same direction and magnitude as the lengthier traditional procedure. Finally, the fact that portable cardiofrequencimeters can be used for this purpose in field conditions and that this procedure can be performed quickly before a training session make the ultra-short-term HRV appealing in sports settings.

Conclusion

To conclude, the results reported herein reveal that lnRMSSD determined in short periods of 1-min, following only 1-min of stabilization, is sensitive to training induced changes in futsal players. This advances the practical use of this measure when monitoring athletes in field conditions.

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Key points

- The ultra-short-term (1 min) natural log of the root-mean-square difference of successive normal RR intervals (lnRMSSD) is sensitive to training effects in futsal players
- The ultra-short-term lnRMSSD may simplify the assessment of the cardiac autonomic changes in the field compared to the traditional and lengthier (10 min duration) analysis
- Coaches are encouraged to implement the ultra-short-term heart rate variability in their routines to monitor team sports athletes

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