2024, Retos, 54, 169-179

Non-Invasive HRV Protocol and New Index to Assess Internal Training Load During Basketball Warm Up

Protocolo de HRV No Invasivo y Nuevo Índice para Evaluar la Carga Interna Durante el Calentamiento en Baloncesto

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Abstract. The aim is to establish an specific, non-invasive, sub-maximum and applicable day-to-day protocol to assess the internal training load (IL) for basketball players using Heart Rate Variability (HRV) analysis before practice or competitions. Another aim is to propose a new IL index as a standardized parameter (%), to manage IL before practice sessions or competition. Twelve amateur male basketball players (age: 26.5 ± 8.8 years) completed HRV tests before a submaximal and intermittent drill (Activity Lay Up Wheel; ALUWIL 6min-test). Players performed a 5on5 scrimmage (MATCH) the following day during 10 min, completing rate of perceived exertion (RPE), total quality recovery (TQR) and wellness questionnaires, and continuous heart rate recordings. Players showed higher values of IL parameters based on heart rate (summatory heart rate zones, SHRZ; and training impulse, TRIMP), higher RPE values and lower recovery values during MATCH than ALUWIL ($p<0.01$). The parameter % of summatory of heart rate zones (SHRZ) showed stronger correlations than SHRZ and TRIMP during MATCH ($p<0.001$), and significant relations with RMSSD (square of the mean root of the adjacent R-R intervals) during the HRV test ($p<0.05$). During the ALUWIL test, %SHRZ shows higher and stronger correlations than SHRZ with RRmean (mean of the R-R intervals) (-.807) but similar than SHRZ with RMSSD. In this specific context, ALUWIL test could offer reliable and applied information as a standardized and integrated protocol to assess internal training load in basketball players using cardiac parameters before practice and games. The parameters RRMean, RMSSD and %SHRZ could be a specific indicator for IL management on basketball. However, more research is needed to validate these proposals in a complex context.
Key words: HRV, internal training load, basketball, heart rate, submaximal test, SHRZ.

Resumen. El objetivo es establecer un protocolo específico, no invasivo, submáximo y aplicable día a día para evaluar la carga interna (IL) en jugadores de baloncesto, a través del análisis de la variabilidad de la frecuencia cardiaca (HRV) antes de los entrenamientos o competición. Otro objetivo es proponer un nuevo índice de carga interna como parámetro estandarizado, para gestionar la carga interna antes de los entrenamientos o partidos. Doce jugadores amateurs de baloncesto (26.5 ± 8.8 años) completaron una prueba HRV antes de un ejercicio submaximo e intermitente (Activity Lay Up Wheel; ALUWIL 6min-test). Al día siguiente los jugadores realizaron una simulación de 5c5 (MATCH) durante 10 minutos. Se completaron registros de esfuerzo percibido (RPE), percepción de recuperación (TQR) y cuestionarios de bienestar, junto con registro continuos de frecuencia cardiaca. Los jugadores mostraron valores más altos en los parámetros de carga interna basados en la frecuencia cardiaca (sumatorio de las zonas de frecuencia cardiaca, SHRZ; e impulso de entrenamiento, TRIMP), valores más altos de RPE y más bajos de recuperación durante MATCH respecto a ALUWIL ($p<0.01$). El parámetro %SHRZ mostro mayores correlaciones que el SHRZ y TRIMP durante MATCH ($p<0.001$) y relaciones significativas con el parámetro RMSSD (raíz cuadrada del valor medio de la suma de las diferencias al cuadrado de todos los intervalos RR sucesivos) en la prueba HRV ($p<0.05$). Durante la prueba ALUWIL, %SHRZ mostró correlaciones más altas y fuertes con el RRmean (media de intervalos RR) que el SHRZ (-.807), pero más similares que el SHRZ con el RMSSD. En este contexto en particular, la prueba ALUWIL podría ofrecer información más fiable y aplicada, como un protocolo estandarizado e integrado para evaluar la carga interna en jugadores de baloncesto antes de los entrenamientos y competiciones, a través de parámetros cardiacos. El parámetro %SHRZ, así como RRMean y RMSSD podrían ser indicadores específicos para gestionar la carga interna en baloncesto. No obstante, más investigación es requerida para validar estas propuestas dentro de un contexto complejo.
Palabras clave: HRV, carga interna, baloncesto, frecuencia cardiaca, test submáximo, SHRZ.

Fecha recepción: 31-10-23. Fecha de aceptación: 07-02-24
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Introduction

External Training Load (EL) is defined as that external physical stimulus applied to the athlete during training (Impellizzeri et al., 2019). The quantification of the athlete's EL offers the possibility of adjusting the loads on a day-to-day basis (Foster et al., 2017), with the aim of reducing the risk of injury to players during the season (Gabbett, 2020). Despite that, a certain EL equal for all players, produces individualized responses (Fox et al., 2018), which are also affected by other biological and environmental variables (Soligard et al., 2016). This individual physiological and psychological response to a specific physical demand is defined as Internal Training Load (IL) (Impellizzeri et al., 2019). IL is conditioned by this specific context and framed within a concept of individualization. The associations between internal and external measures of training load are important in understanding the training process and the validity of specific internal measures (Ferioli et al., 2021; McLaren et al., 2018). Therefore, by individually assessing the relationships between both loads (Impellizzeri et al., 2019; Soligard et al., 2016) it offers specific information on each player in relation to their performance and provides the coaches with a specific tool for load management and adaptation processes (West et al., 2021), recovery (Halson et al., 2014; Impellizzeri et al., 2019), and injury prevention in training (Gabbet, 2020).

One of the current procedures used for measuring IL in sports is Heart Rate Variability (HRV) analysis and is considered an effective tool to monitor the adaptation to a daily load and training program (Lundstrom et al., 2023; Soligard et al., 2016). HRV is defined as the fluctuations in the time interval between consecutive beats. There are mainly two types of analyses for assessing HRV based on the time domain or on the frequency domain, in accordance with the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Malik et al., 1996). HRV could be a valid and reliable index to assess the autonomic balance between the sympathetic and parasympathetic branches of the autonomic nervous system (ANS) (Laborde et al., 2017). HRV is described as a good index of the body's capacity to tolerate and adapt to an exercise stimulus (Aubert et al., 2003), that could become an alternative as an internal load parameter (Plews et al., 2017), as a non-invasive technique and easy to use, even for professional sports (see the review of Bellenger et al., 2016).

Nevertheless, cardiac parameter measurement systems such as thoracic bands might be uncomfortable for athletes and accumulate many recordings errors. In addition, the HRV tests are often performed at rest, interfering with the training or competition routines (Barreto et al., 2023). For this reason, a current trend is to subjectively evaluate the internal load with validated cognitive scales (Coyne et al., 2022), such as the Rating of Perceived Exertion (RPE; Borg, 1998).

Basketball is a team sport that involves high levels of IL in players (Petway et al., 2020). It is common for IL to be integrated into an overall training protocol in order to obtain information about the performance of each individual player (Foster et al., 2017). IL has been assessed for basketball in different contexts, like competitions (García et al., 2023; García et al., 2022; Garcia-Santos et al., 2019; Portes et al., 2021) or during training sessions, (Espasa-Labrador et al., 2021; López-Laval et al., 2022; Sansone et al., 2021) with HRV being an applicable tool for the assessment of physical condition in athletes (Morales et al., 2014; Ramos-Campo et al., 2017). In a competitive sports context, in individual modalities, proposals have been made in which HRV tests are performed before and after the sports practice (Barreto et al, 2023; Guillaumes et al., 2018), and in the specific case of basketball, HRV records have also been described during training, but without a previous assessment (Zamora et al., 2021). Obtaining individual HRV values before training or competition would allow the staff to modulate the training load for each player in a healthy way (Schwellnus et al., 2016).

The main aim of this study is to propose a specific, standardized, active, and integrated protocol for basketball players using HRV analysis during warm-up routines to assess possible associations of IL during previous practices and competition. This test should be performed on the basketball court and should involve the players performing a drill with the ball, as well as decision-making. It has to be non-invasive, sub-maximum, applicable day-to-day, and it always has to use the same external load in order to analyse possible individual differences of internal load. Another specific aim of this study is to propose an internal load parameter (0 to 100%), which could allow an easier and better IL management.

Methods

Participants

Twelve amateur male basketball players from the same team at 4th state division (Copa Catalunya, Catalan Basketball Federation) participated in the study, with a mean age of 26.5 (SD: 8.8) years, a mean height of 190.2 (SD: 7.4) cm, and a mean weight of 92.1 (SD: 6.2) kg. During the study, players trained regularly throughout the competitive period of the 2018-2019 season. The study was carried out within the framework of a university research group and was approved by the corresponding ethics committee. Data were treated anonymously according to the Helsinki Declaration (Fortaleza, 2013), and all players gave their written informed consent to participate in the study.

Material and Instruments

A custom-made computer program (Fitlab® Team; Barcelona, Spain) was used for recording data about the internal load, the two questionnaires, and cardiac parameters. This application runs on an iPad device (Apple) and can be connected to several cardiac chest bands (up to fifteen) via Bluetooth. Heart rate and heart rate variability (HRV) were recorded using ten Polar H7 chest band sensors (Polar Electro Oy, Kempele, Finland). After the data were saved, the device sent them by wireless to a remote server where they were processed. The system can perform synchronized recordings of all players in each session, and check the quality of data in real time. We will describe the calculations with cardiac parameters below in the data analysis section. The questionnaires recorded by the software are described below:

- Rating of Perceived Exertion (RPE) scale. An adapted version of RPE based on Borg (1998) was used. It consists of a single question (“What is the effort level that was involved the last training session or exercise?”), for which players respond according to a scale ranging from 0 (nothing at all) to 10 (maximal effort). The RPE was completed daily after the ALUWIL (Activity Lay Up Wheel/Internal Load) test and the 5 on 5 scrimmage (MATCH) and was reflective of the response to the immediately preceding training load.

- Total Quality Recovery (TQR) scale. An adapted version of TQR based on Kenttä and Hassmén (1998) was used. It consists of a single question (“What is your level of recovery as regards to the last training session or exercise?”), for which players respond according to a scale ranging from 0 (nothing at all) to 10 (maximal). TQR was completed daily after the ALUWIL and MATCH and was reflective of the response to the immediately preceding training load.

- Wellness Questionnaire (Figure 1). A custom-made cognitive questionnaire was used, based on previous recommendations by Hooper and Mackinnon (1995) and previous indications by McLean et al. (2010). Wellness Questionnaire consisted of a single question ("Set your level of recovery since the last training session or 5 on 5 scrimmage"), and consisted of 5 questions relating to perceived fatigue, general muscle pain, sleep quality, nutrition/hydration level, and emotional state. Each question was scored on an eleven-point scale (scores of 0 – 10, with 0 and 10 representing very poor and very good wellness ratings, respectively (1-point increments). Total Wellness score was calculated as the mean value of the five sub-scores. The Wellness questionnaire was completed daily before the ALUWIL and MATCH and was reflective of the response to a preceding training load from the previous daily session.

Figure 1. Screenshot that shows the subscales of the Wellness Questionnaire, as responded by players using the custom-made App (Fitlab® Team).

Procedure

All players performed, simultaneously in a group and during seven weeks, the three parts of the protocol on two consecutive days of a regular competitive week: one for two tests and one for practice assessment. Altogether, seven tests and seven practice assessments were performed (see Figure 2). Players wore the cardiac thoracic bands during the three drills, and cardiac activity was recorded for each one using Fitlab software. On the first day, players performed consecutively the REST test (1st part) and then the ALUWIL Test (2nd part); and on the second day they performed the 5on5 scrimmage drill (3rd part):

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
practice	practice	off	PRE-TEST + ALUWILL TEST & practice	PRACTICE ASSESSMENT	off	Game

Figure 2. Competitive week schedule and protocol test

a) REST test. HRV was tested for 5 minutes with the participants at rest, in supine position, with the eyes closed, with no activity, with natural breathing, and without speaking or making any movement, corresponding to the traditional 5min-HRV Test protocol (Moreno et al., 2015).

b) ALUWIL Test. This test (ALUWIL), based on the "Activity Lay Up Wheel", is non-invasive, sub-maximum, applicable day-to-day drill, it always assumes the same external load in order to analyse possible individual differences in internal load, and allows recovery periods for the players. ALUWIL Test is performed for 6 minutes and without a warming up period: 6 players will be on each side of half court, and 6 of them with a ball. It starts from the right side, where the first player with a ball, performs an open dribble with the outer foot and performs 3 dribbles to finalize an entrance to the right. After finishing the lay-up, they go to the left corner at half court and at the moment when a team-mate starts dribbling, begin to run to basket to rebound. After rebounding, he will dribble to the right corner again to start the exercise. Each player with a ball initiates the entry at the moment the player who precedes him performs the 2nd dribble. The exercise is carried out for 1'30 ". During the next 1'30", after the second dribble, the player with a ball will do a 2-point throw. In the following 1'30" he will pass the balls to the players in the row on the left side, who will start the lay-up wheel on this side. In the last 1'30", after the second dribble, the player with a ball will do a 2-point throw. (See Figure 3).

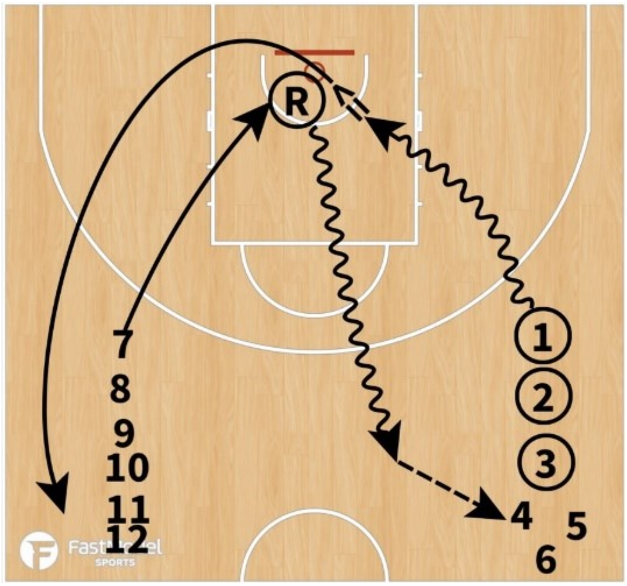

Figure 3. Scheme of the procedure to perform the Activity Lay Up Wheel corresponding to the ALUWIL Test. **X** player without ball; **X** player with ball; player motion without ball; pass player motion with ball (dribling); => shoot

c) 5on5 scrimmage drill (MATCH). After a warm-up consisting of a protocol of joint mobility and dynamic stretching, as well as the performance of the ALUWILL (without being tested), all players perform a standardized competitive exercise (Schelling and Torres-Ronda, 2013), which consists of a 5 on 5 basketball scrimmage simulation in the full court, during a period of 10 minutes (like one of the four periods of a basketball game for the International Basketball Federation – FIBA - rules). Specific offensive and defensive instructions were given to players by the coach, and rules were same as during official competition. Thus, the REST and ALUWIL tests were performed consecutively the same day, and the MATCH was performed the following day to assess possible associations of the REST and ALUWIL tests previous to practice or competition. Players completed the questionnaires individually 15-30 minutes before (Wellness Questionnaire), or after (RPE and TQR) each day-session (Miranda et al., 2023).

Data analysis

The cardiac parameters from RR intervals and all IL parameters were processed using specific software designed in a MATLAB environment (James & Wixted, 2011). HRV parameters were calculated according to the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Malik et al., 1996), using a custom R-wave peak detection algorithm in Matlab (MathWork, USA). A maximum signal error of 10% was accepted and filtered (Moreno et al., 2015) . For the time domain analysis, the mean of RR intervals (RRmean), the standard deviation of all RR intervals (SDNN), and the root mean square of differences (RMSSD) of successive RR intervals were calculated. For frequency domain analysis, all RR series were re-sampled at 3 Hz using a cubic spline prior to the HRV analysis. The power spectrum of the re-sampled time series was estimated using the Fast Fourier Transformation after removing the mean of the time series and multiplying the time series by a Hann window. The power of the very low frequency band (VLF) was estimated by integrating the power spectrum for frequencies lower than 0.04 Hz. Accordingly, the power of the low frequency band (LF) was computed in the band 0.04 – 0.15 Hz, and the power of the high frequency band (HF) was computed in the band 0.15 – 0.4 Hz. Additional calculations included the LF/HF ratio, and LF and HF values expressed in normalized units (LFnu and HFnu) (Moreno et al., 2015). The parameters used in our study that are based on the recorded heart rate values are described below:

Training impulse (TRIMP). The following formula was applied to determine internal training load using TRIMP (Banister, 1991):

TRIMP = (duration in min) * (HRex – HRrest) / (HRmax – HRrest) * 0.64e1.92x,

where HRex = average HR during exercise; HRrest = HR at rest; HRmax = maximal HR; e =2.712; and x = (HRex - HRrest) / (HRmax - HRrest). TRIMP is measured in arbitrary units (AU).

Summated-heart-rate-zones (SHRZ). The following formula was applied to determine internal training load using SHRZ (Edwards, 1993):

SHRZ = (min in zone 1 x 1) + (min in zone 2 x 2) + (min in zone 3 x 3) +

+ (min in zone 4 x 4) + (min in zone 5 x 5),

where zone 1 = 50–60% of HRmax; zone 2 = 60–70% of HRmax; zone 3 = 70–80% of HRmax; zone 4 = 80–90% of HRmax; zone 5 = 90–100% of HRmax. SHRZ is measured in arbitrary units (AU). HRMax is individually estimated by the HR device software. Percentage of summated-heart-rate-zones (%SHRZ). %SHRZ is proposed as an internal load index. It is standardized as a percentage (0 to 100%) to allow an easier and better IL comparison between players and sessions. The following formula was applied to determine internal training load using %SHRZ:

%SHRZ = [(min in zone 1 x 1) + (min in zone 2 x 2) + (min in zone 3 x 3) +

+ (min in zone 4 x 4) + (min in zone 5 x 5)] / (min exercise x 5) * 100

where zone 1 = 50–60% of HRmax; zone 2 = 60–70% of HRmax; zone 3 = 70–80% of HRmax; zone 4 = 80–90% of HRmax; zone 5 = 90–100% of HRmax; and min exercise = total duration of exercise. %SHRZ is measured in percentage (%).

Statistical Analysis

MANOVA analysis for repeated measures was applied to test the overall differences between the REST Test, ALUWIL Test, and MATCH on the IL parameters. Because normality tests indicated that some HRV parameters did not follow normality, Wilcoxon signed-rank non-parametric test for repeated measurements was performed in order to compare mean values between exercises on the IL parameters when MANOVA was significant. For the same reason, Spearman non-parametric correlations for IL parameters and scores between the three parts of the protocol were calculated. Results were expressed in terms of mean (M) and standard deviation (SD), or standard error of the mean (SEM). All analyses were carried out using SPSS statistical package (IBM, USA), and values were considered statistically significant when $p<0.05$.

Results

Table 1.
Heart rate, HRV and IL values (means and SD) for the three steps, REST, ALUWIL and MATCH.

(Mean ± SD)	REST		ALUWIL		MATCH		p
HR mean	74,08	±10,13	119,47	±6,39	142,95	±15,42	<.001
HRmax							
RRmean	823,46	±107,83	503,62	±28,22	424,46	±47,79	<.001
SDNN	67,15	±20,26	23,00	±5,80	43,62	±25,07	<.001
RMSSD	34,54	±18,51	7,15	±2,34	8,54	±8,72	<.001
LF	1890,15	±1249,95	79,31	±61,25	59,62	±80,92	.001
HF	441,77	±487,67	8,08	±4,94	32,15	±74,57	.014
SHRZ			8,69	±2,10	62,92	±41,54	.001
%SHRZ			34,62	±8,27	70,15	±15,88	<.001
TRIMP			14,15	±1,57	35,85	±23,42	.005

HRmean: mean of instantaneous heart rate; HRmax: maximal heart rate values; RRmean: mean of RR interval; SDNN the standard deviation of all RR intervals; RMSSD: the root mean square of differences of successive RR intervals; LF: low frequency; HF: high frequenc; SHRZ: summated-heart-rate-zones; %SHRZ: percentage of SHRZ; TRIMP: training impulse.

Table 1 shows IL parameters (means and SD) for the three parts of the protocol, REST Test, ALUWIL Test, and MATCH. Significant differences were found between the three steps for all parameters according to a MANOVA for repeated measurements. Figures 4, 5, and 6 represent the significant results when comparing IL parameters with the

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steps by pairs, according to Wilcoxon signed-rank non-parametric test for repeated measurements. Figure 4 shows that RRmean for the REST was 823.46ms (SD 107.83), for the ALUWIL it was 503.62ms (SD 28.22), and for the MATCH it was 424.46ms (SD 47.79), with these values being significantly higher for the REST than for the ALUWIL and higher for the ALUWIL than for the MATCH ($p<0.001$). Heart rate values show exactly the same significance, given that they are inversely proportional to RRmean values.

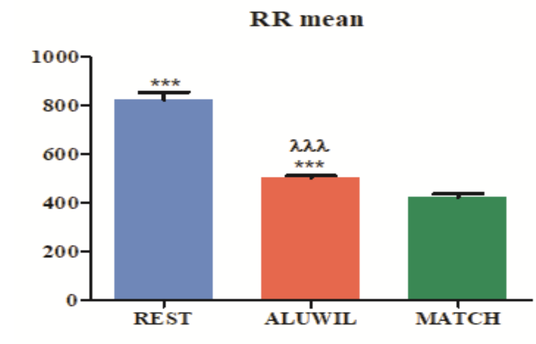

Figure 4. RRmean (mean and SEM) for the 3 steps of the study. REST: 5min-HRV test; ALUWILL: Activity Lay Up Wheel/Internal Load Test; MATCH: 5x5 basketball match simulation. (***p<0.001 vs. MATCH; λλλp<0.001 vs. REST).

Figure 5 shows IL parameters based on HRV analysis for the three parts of the protocol. On the one hand, the HRV parameters SDNN, RMSSD, LH, and HF were significantly higher in the REST step than in the ALUWIL ($p<.001$) and MATCH ($p<0.05$). On the other hand, SDNN was higher in the MATCH than in the ALUWIL ($p=0.015$), but there were no statistically significant differences for RMSSD, LF, and HF, probably due to a high SEM and SD in MATCH. Figure 6 shows IL parameters based on continuous heart rate for the ALUWIL and MATCH. There are no values for the REST, as it only makes sense to calculate these parameters during the effort. All parameters were significantly higher in the MATCH than in the ALUWIL ($p=0.005$ for the TRIMP; $p=.001$ for SHRZ; $p<.001$ for %SHRZ).

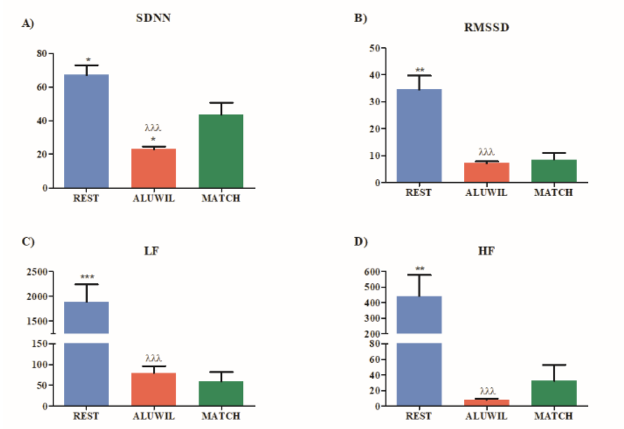

Figure 5. IL parameters based on HRV analysis (mean and SEM) for the three steps of the study. REST: 5min-HRV test; ALUWILL: Activity Lay Up Wheel/Internal Load Test; MATCH: 5x5 basketball match simulation. (*p<0.05 for REST>MATCH, and MATCH>ALUWIL; **p<0.01 for REST>MATCH; ***p <0.001 for REST>MATCH; λλλp<0.001 for REST>ALUWIL).

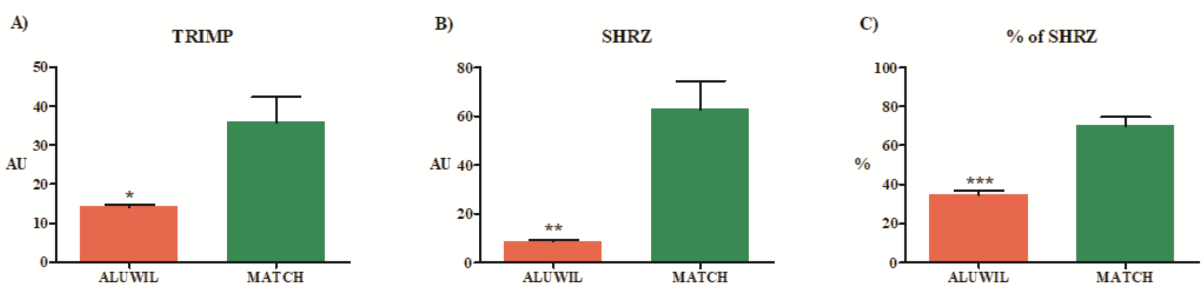

Figure 6. IL parameters based on heart rate (mean and SEM) for ALUWIL and MATCH steps. A) SHRZ (summated-heart-rate-zones), B) %SHRZ (percentage for summated-heart-rate-zones), C) TRIMP (training impulse). ALUWILL: Activity Lay Up Wheel/Internal Load Test; MATCH: 5x5 basketball match simulation. (*p=.005; **p=.001; ***p<.001; MATCH>ALUWIL).

Correlations between the three part are shown in Tables 2-4. Table 2 shows the correlations between the REST and MATCH. For traditional IL parameters, %SHRZ in the MATCH had a higher correlation (-.0487; $p=.09$) with a REST parameter (RMSSD). No significant correlations were observed for SHRZ or TRIMP. The only significant correlation for parameters based on HRV was the one observed between RRmean in the MATCH and RMSSD in the REST (-.0487; $p=.09$). Table 3 shows significant correlations between the ALUWIL and REST; for example in the RMSSD (0.782; $p<.01$), LF (0.593; $p<.05$), or HF (0.682; $p<.05$). The RMSSD correlates with other parameters, and SHRZ and %SHRZ show similar significant correlations, and TRIMP does not correlate with any parameter. Table 4 shows the correlations between the ALUWIL and MATCH. Significant correlations can be observed in the diagonal of the Table for the RRmean, RMSSD, LF, HF, and %SHRZ. This latter parameter shows significant correlations with HRV-based parameters, such as the RRmean, RMSSD, LF, and HF, while SHRZ and TRIMP do not show any significant correlation.

In Table 5 it can be observed that %SHRZ shows a high correlation of 0.982 with SHRZ. However, it is not the same parameter, as it shows higher and more significant correlations than SHRZ for parameters based on HRV (RRmean, LF and HF), except for RMSSD, for which it shows a similar correlation. TRIMP only shows a significant correlation with the HRV-based SDNN parameter.

Table 2.
Spearman correlations between REST and MATCH for IL parameters

	MATCH							
REST	RRMean	SDNN	RMSDD	LF	HF	SHRZ	%SHRZ	TRIMP
RRMean	,214	,437	,165	,261	,147	,275	-,214	,315
SDNN	-,044	,162	-,075	,008	-,111	,168	,044	,234
RMSSD	,487*	,380	,332	,350	,337	-,127	-,487*	0,000
LF	,368	,223	,221	,319	,344	-,226	-,368	-,173
HF	,423	,380	,282	,393	,338	-,110	-,423	,022

RRmean: mean of RR intervals; SDNN: standard deviation of all RR intervals; RMSSD: root mean square of differences of successive RR intervals; LF: low frequency; HF: high frequency; SHRZ: summated-heart-rate-zones; %SHRZ: percentage of SHRZ; TRIMP: training impulse. (*p=0.09)

Table 3.
Spearman correlations between ALUWIL and REST for IL parameters.

	ALUWIL							
REST	RRMean	SDNN	RMSDD	LF	HF	SHRZ	%SHRZ	TRIMP
RRMean	,523	-,119	,293	,099	,212	-,548	-0,534	,487
SDNN	-,066	,237	,338	,319	,246	-,523	-,468	-,091
RMSSD	,313	,162	,782**	,542*	,719**	-,649*	-,610*	-,043
LF	,066	,414	,542	,593*	,542	-,403	-,386	-,337
HF	,226	,359	,690**	,604*	,682*	-,562*	-,554*	-,164

RRmean: mean of RR intervals; SDNN: standard deviation of all RR intervals; RMSSD: root mean square of differences of successive RR intervals; LF: low frequency; HF: high frequency; SHRZ: summated-heart-rate-zones; %SHRZ: percentage of SHRZ; TRIMP: training impulse. (*p<0.05; **p<0.01)

Table 4.
Spearman correlations between ALUWIL and MATCH for IL parameters.

	MATCH							
ALUWIL	RRMean	SDNN	RMSDD	LF	HF	SHRZ	%SHRZ	TRIMP
RRMean	,726**	,613*	,511	,683*	,613*	-,088	-,726**	,010
SDNN	-,025	-,119	-,331	,040	-,050	-,323	,025	-,311
RMSSD	,841**	,532λ	,682*	,560*	,649*	-,344	-,841**	-,194
LF	,566*	,437	,313	,608*	,507	-,248	-,566*	-,176
HF	,816**	,590*	,563*	,657*	,614*	-,274	-,816**	-,102
SHRZ	-,531	-,479	-,274	-,440	-,365	,145	,531λ	,040
%SHRZ	-,540λ	-,548λ	-,251	-,514λ	-,386	,066	,540λ	-,056
TRIMP	,017	,310	,314	,145	,168	,451	-,017	,407

RRmean: mean of RR intervals; SDNN: standard deviation of all RR intervals; RMSSD: root mean square of differences of successive RR intervals; LF: low frequency; HF: high frequency; SHRZ: summated-heart-rate-zones; %SHRZ: percentage of SHRZ; TRIMP: training impulse. (*p<0.05; **p<0.01; λp<0.06)

Table 5.
Spearman correlations between IL PARAMETERS for ALUWIL.

	ALUWIL		
ALUWIL	SHRZ	%SHRZ	TRIMP
RRMean	-,777**	-,807**	-,028
SDNN	-,469	-,497	-,631*
RMSSD	-,726**	-,686**	-,026
LF	-,684**	-,725**	-,543
HF	-,636*	-,667*	-,124
SHRZ		,982***	,213
%SHRZ			,228

RRmean: mean of RR intervals; SDNN: standard deviation of all RR intervals; RMSSD: root mean square of differences of successive RR intervals; LF: low frequency; HF: high frequency; SHRZ: summated-heart-rate-zones; %SHRZ: percentage of SHRZ; TRIMP: training impulse. (*p<0.05; **p<0.01; ***p<0.001)

As regards the IL questionnaires, a MANOVA analysis for repeated measurements shows that players perceive less effort immediately after the ALUWIL (RPE=3.08; SD=2.37) than the MATCH (RPE=5.92; SD=2.06; p=.003). At the same time, they also perceived a better recovery immediately after the ALUWIL (TQR=7.85; SD=1.28) than the MATCH (TQR=5.23; SD=1.83; p<.001). On the other hand, players perceive more wellness immediately before the ALUWIL (Wellness total score=7.05; SD=1.60) than the MATCH (Wellness total score =6.28; SD=1.31; p=.036).

Figure 7 shows the IL questionnaires scores (Wellness, RPE and TQR questionnaires) for ALUWIL and MATCH. Significant differences were found between the ALUWIL and MATCH for "Muscular-wellness" subscale (6.69±2.5 and 5.08±1.94, respectively; p=0.015), RPE (3.08±2.3 and 5.92±2.06, respectively; p=0.01), and TQR (7.85±1.28 and 5.23±1.83, respectively; p=0.003).

Table 6 shows the correlation values of IL parameters, based on HR and HRV analysis, with questionnaires scores (Wellness subscales, RPE and TQR) for the ALUWIL. On the one hand, the questionnaire scores that show significant correlations with IL parameters are RPE and the subscales of Wellness of Fatigue, Sleep and Emotional. On the other hand, two parameters based on HR that show very similar correlations are SHRZ and% SHRZ, whereas TRIMP does not have any significant correlation. Additionally, the only IL parameters based on HRV analysis that show significant correlations are RRmean and RMSSD.

No significant correlations were found in MATCH between the same IL parameters and the same questionnaire scores.

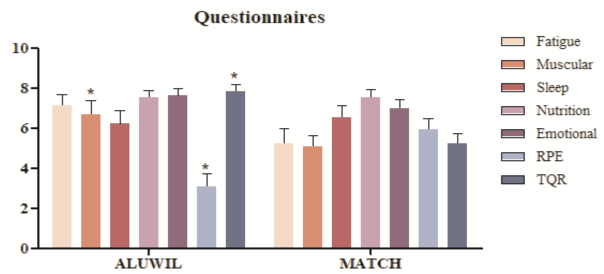

Figure 7. IL questionnaires scores (mean and SEM) for ALUWIL and MATCH steps. Wellness questionnaire: scales of fatigue, muscular, sleep, nutrition and emotional. RPE: Rated Perceived Exertion. TQR: Total Quality Recovery. ALUWILL: Activity Lay Up Wheel/Internal Load Test; MATCH: 5x5 basketball match simulation. (*p<0.05 vs. MATCH).

Table 6.
Spearman correlations between IL parameters based on HRV and questionnaires scores for ALUWIL step

	QUESTIONNAIRES							
IL Param	Fatigue	Muscular	Sleep	Nutrition	Emotional	WQ	RPE	TQR
RRMean	,647*	,233	,586*	,305	,449	.386	-,587*	,121
SDNN	,234	,028	,141	-,170	,380	.142	,099	-,046
RMSSD	,633*	,270	,569*	,081	,145	.316	-,572*	,142
LF	,401	,033	,103	,065	,060	.111	-,154	-,157
HF	,537	,258	,351	,151	,130	.262	-,478	-,012
SHRZ	-,742**	-,391	-,712**	-,297	-,565*	-.563*	,620*	-,271
%SHRZ	-,743**	-,389	-,656*	-,323	-,567*	-.541*	,592*	-,222
TRIMP	-,013	,280	,204	,471	,022	.255	-,425	,182

Wellness Questionnaire subscales: Fatigue, Muscular, Sleep, Nutrition and Emotional; WQ: Wellness Questionnaire total score; RPE: Rating of Perceived Exertion scale; TQR: Total Quality Recovery scale; IL Param: HRV and HR IL parameters. (*p<0.05; **p<0.01)

Discussion

The main findings of this study are that the ALUWIL protocol could be performed as an active and integrated protocol to assess IL for basketball players before practice or competition, using cardiac parameters through a specific drill during training or warmup routines. Secondly, HRV analysis parameters for RRMean and RMSSD could provide significant information to assess IL during a submaximal effort with intermittent, but controlled, loading for basketball. And on that context, %SHRZ could be used as an IL index (0 to 100%) to allow an easier and better IL comparison between players and sessions.

As regards the first objective, Table 1 shows that the mean value of heart rate (HR) is higher in the MATCH than in the ALUWIL ($p<.001$). The same goes for traditional IL parameters based on HR such as SHRZ ($p = .001$) and TRIMP ($p = .005$), in accordance with Scanlan et al. (2014). Logically the level of effort is also higher in those two parts of the protocol than in REST ($p<.001$), since there is no load on this one. These results consistently confirm that the effort level and external load are higher in MATCH than in ALUWIL. This agrees with the perception of the players, who express that they have made significantly less effort and that they have recovered significantly better after ALUWIL than MATCH. These results are not relevant in the sports context, but they positively assess and support the adequacy of the proposed tests "activity lay-up wheel" as a submaximal exercise for basketball. ALUWIL (Activity Lay Up Wheel/Internal Load Test) consists of evaluating the IL from cardiovascular and cognitive parameters while the players always perform at same level of EL, and that does not interfere in their daily practice. In contrast, IL has been traditionally evaluated from some tests like Yo-Yo Intermittent Recovery Test (Krustrup et al, 2003), which imply the execution of a similar maximum effort for all players. This test is aimed for intermittent sports, such as basketball, and at different competitive levels (Abad et al., 2016). Although this test is physiologically oriented to the sport modality, is not specific in training or competition contexts. In addition, it is considered an invasive test since its load can be maximal, altering regular workouts and practices. In this sense, one of the main advantages of ALUWIL could be that players can regularly perform this test based on the level of regular effort in the practice sessions. Another reason to use it instead of the usual resting HRV test is that, as it requires a certain level of effort, the HRV parameters show stronger correlations with those of the "match" situation. In Table 4, there are 19 significant correlations (all higher than 0.55) observed between the HRV parameters of the ALUWIL test and the "match" (see Table 4). In contrast, there are only two significant correlations between REST and the "match" (see Table 2).

IL could be evaluated during the ALUWIL from HRV analysis and from other cardiovascular parameters based on the continuous recording of HR. Table 1 shows how players increase around 45 beats per minute in ALUWIL compared to REST ($p<.001$). This is consistent with the effort level that players have made during the test. At the same time, players show a significant increase of around 23 beats in MATCH, indicating that during ALUWIL test they are experiencing a lower submaximal load ($p<.001$). These same results can be deduced from Figure 4 for RRmean parameter ($p<.001$). RRmean shows inverse values, but proportional to HR, since the HR is calculated from the RR interval (time interval between consecutive heat beats), RR being the raw data recorded by Polar thoracic bands, from which the other parameters indicated in Table 1 are calculated.

As regards traditional IL parameters, TRIMP (Banister, 1991) and SHRZ (Impellizzeri et al., 2004) present higher significant values in MATCH than in ALUWIL (see Figure 6), indicating that players experience a higher level of effort during the game simulation. There are more results that support that the ALUWIL Test represents a submaximal load level. Same level of external load on players is reflected in submaximal and individual values of IL (Bourdon et al., 2017). But both TRIMP and SHRZ are parameters measured in arbitrary units (AU) and are difficult to compare between different players and between different situations. For this reason, it's proposed an IL index, %SHRZ, as a parameter that solves this problem by presenting values as a percentage (from 0 to 100%). The % SHRZ parameter refers to the percentage of time in which the athlete strives to the maximum, with respect to the total duration of the exercise. That is, the percentage of time the athlete spends between 90 to 100% of his HRMax (zone 5 according to Edwards, 1993). For most athletes, %SHRZ will have values between 20% and 100% (between zones 1 and 5, according to Edwards, 1993), as they will typically show HR values above 50% of their HRMax.

Figure 6 shows %SHRZ better statistical significance than SHRZ and that of TRIMP. There are other data that could show this better adjustment of %SHRZ to explain IL. Its higher correlation (-.487; $p=.09$) in MATCH with REST for RMSSD, while SHRZ and TRIMP do not show any correlation with a significance tendency, as shown in Table 2. However, Table 5 shows %SHRZ a high correlation (0.982) with SHRZ. SHRZ is based on the time taken in predefined HR intensity zones according to 5 discrete HR zones in relation to the maximum HR. A multiplier accompanies each HR zone that gives greater weight to the highest relative HR responses, typical of acyclic sports such as basketball (Scanlan et al., 2014), and also valid for the control of the IL of the athlete (Soligard et al., 2016). However, %SHRZ, provides better results than SHRZ, showing higher and more significant correlations to parameters based on HRV like RRmean (-.807). For RMSSD it shows a similar significant correlation. These results shown by %SHRZ are consistent, since the negative sign of the correlation coefficients indicates that a higher level of effort (indicated for a higher value of %SHRZ) is related to lower cardiac variability. The effectiveness of HRV analysis has long been recognized as a quick and non-invasive individual assessment of the adaptation to a regular physical exercise (Javaloyes et al., 2020) and as a marker for the possible influence of fatigue states, overexertion and stress processes (Botelho et al., 2022). In this sense, HRV is considered as an effective tool to monitor adaptation to a daily load and training program (Soligard et al., 2016). Results show that could be possible to assess HRV consistently during the underlying effort in the ALUWIL test. In this sense, Table 3 shows significant correlations between the ALUWIL and REST test with the RMSSD (0.782; p<.01), and %SHRZ shows similar significant correlations to SHRZ with HRV-based parameters, while TRIMP does not. Likewise, in order to verify the consistency of HRV in ALUWIL, significant correlations with MATCH can be observed for RRmean, RMSSD, and %SHRZ (Table 4). This latter parameter shows significant correlations with HRV-based parameters, like RRmean and RMSSD, while SHRZ and TRIMP do not show any significant correlation. According to those results, HRV could be an alternative and complementary parameter for assessing IL load in athletes (Plews et al., 2017). HRV is considered a valid and reliable parameter to assess the balance between the sympathetic and the parasympathetic systems (Shaffer and Ginsberg, 2017), and an index of autonomic resilience, since it reflects the ability to recover from exposure to both physical and psychological stressors. In addition, HRV is described as a good indicator of the body's capacity to tolerate and adapt to an exercise stimulus (Aubert et al., 2003).

In relation to IL cognitive variables, Table 6 shows significant correlations of the RPE, WQ (Wellness total score), Fatigue, Sleep, and Emotional (Wellness subscales) with IL HR-based parameters (SHRZ, %SHRZ) and with HRV-based parameters (RMSSD, RRmean). RPE was completed after the ALUWIL test, reflecting the response to the immediately preceding training load. On the one hand, its correlation with SHRZ (.620) and %SHRZ (.592) has a positive sign, indicating more perception of effort when these IL HR-based parameters indicate more effort (more IL). On the other hand, RPE shows a negative correlation with the RRmean (-.587) and RMSSD (-.572), indicating more perception of effort when these IL HRV-based parameters indicate less cardiac variability (related to more IL). These results support that RPE is a useful index for monitoring IL (Lupo et al., 2017). Its use after the session is a valid individualized indicator, taking into account recovery strategies when the player is very tired (Weiss et al., 2017).

As regards the Wellness Questionnaire, it was completed before ALUWIL test and reflects the response to a preceding training load from the previous daily session. In general, the results are very consistent with those found for RPE. In this case, Table 6 shows significant negative correlations of SHRZ and %SHRZ with WQ (total score) and fatigue, sleep, and emotional wellness sub-scales, indicating the higher the IL level the lower is the perception of well-being with respect to the recovery of the previous day. On the other hand, the same HRV parameters (RMSSD and RRmean) show positive correlations with fatigue, sleep, and emotional wellness sub-scales, indicating more cardiac variability (associated with less internal load) when the perception of well-being is higher as regards the recovery of the previous day. Recovery is regarded as a multifaceted, physiological, and psychological, restorative process relative to time (Kellmann et al., 2018). Fatigue is a condition of increased tiredness due to physical and mental effort (Halson, 2014). This can be compensated with recovery, which re-establishes the allostatic balance and psychological states. Thus, recovery is an essential process to both prevent injuries and to improve stress management (Heidari et al., 2018). Thus, for athletes, an adequate balance between stress and recovery is also essential to achieve continuous high-level performance (Kellmann et al., 2018).

However, this study has some limitations. The amateur level of the sample has the advantage to get an open context to apply the protocol, not as could happen on a professional one during a competitive period, but there is the lack of a closed control and capacity to manage players routines (such as diet or sleep) that could affect some of the test results. As well, HRMax is individually estimated by the HR bands software, and not tested in an effort maximal test. The aim of this study is to explore reliable protocols and parameters to propose non-invasive, easier, and applied IL real time evaluation and assessment methods. Results might be interpreted in this specific context, as starting point for future research to confirm the findings presented here.

Conclusion

The ALUWIL test could be an active and integrated protocol to assess IL for basketball players using cardiac parameters previous to practice and competition. %SHRZ index (0 to 100%) is related to HRV parameters and could allow an easier and better IL comparison than traditional parameters between players and sessions.

Practical applications

Coaches and staff should be able to manage the training loads within the upcoming session or for the next sessions, balancing between IL and EL with the proposed protocol without the disadvantages of resting or maximal evaluations as it has been doing so far. Being able to count on applicable and reliable information prior to training or competition can allow us to modulate the workload of each of the team's players according to their needs, in order to adequately achieve the training objectives or better performance during the competition (Guerrero et al., 2023). According to a consensus statement for monitoring athlete training loads (Bourdon et al., 2017), the emergence of new technologies and new analytical approaches could bring about more powerful tools to assess performance and risk of injury. As used on this study, real time, non-invasive and reliable current technology is able to provide preventive and recovery strategies, and monitor recovery processes.

Acknowledgments

This work was supported by Grants PID2019-107473RB-C21funded by MCIN/AEI/10.13039/501100011033 by the Spanish Government, and 2021SGR-00806 funded by the Catalan Government. There is no conflict of interest.

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