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Automated observation: heart rate variability and its relationship with performance-related psychological variables in young swimmers

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Título: Observación automatizada: la variabilidad de la frecuencia cardíaca y su relación con las variables psicológicas determinantes del rendimiento en nadadores jóvenes.
Resumen: La correcta interpretación de los marcadores de rendimiento desde una perspectiva psicofisiológica es importante para el desarrollo de los atletas en etapas formativas. Este trabajo contiene dos objetivos. El primero es analizar la relación de la variabilidad de la frecuencia cardíaca (VFC) con las variables psicológicas: calidad de sueño, autoestima y estados de ánimo en jóvenes nadadores de una escuela profesional. El segundo objetivo es estudiar la relación de la VFC y determinantes psicológicos con el rendimiento. Esta se compuso 9 nadadores (11.7 ± 1.4 años) basada en un método de muestreo a propósito. Las mediciones fueron efectuadas una vez por semana durante tres semanas de entrenamiento. El análisis estadístico muestra como la dimensión de ansiedad correlacionó negativamente con el logaritmo natural de banda de alta frecuencia (Ln HF) y positivamente con el logaritmo natural de la banda de muy baja frecuencia (Ln VLF) de forma significativa. No se encontraron relaciones para las variables autoestima y calidad de sueño. El tiempo en la prueba de rendimiento fue asociado negativamente con indicadores de la actividad parasimpática. Estos resultados sugieren que la VFC podría ser una herramienta válida para la predicción del rendimiento y mejora de la interpretación de la ansiedad.
Palabras clave: Calidad de sueño; estados de ánimo; autoestima; rendimiento.

Abstract: Correct interpretation of performance markers from a psychophysiological perspective is important in young developing athletes. This study had two objectives. The first was to analyze the relationship between heart rate variability (HRV) and the psychological variables sleep quality, self-esteem, and mood states in young swimmers from a professional swimming club. The second was to study the relationship between performance and HRV and psychological determinants. The sample was composed of nine swimmers (11.7±1.4 years) base on purposive sampling method. Data were collected once a week during training sessions for 3 weeks. The statistical analysis showed that anxiety was negatively correlated with the high frequency component of HRV (Ln HF) and positively correlated with the very low frequency component (Ln LVF). No significant correlations were observed for self-esteem or sleep quality. Performance in a 200-m freestyle event was negatively correlated with the parasympathetic HRV indices. Our results suggest that HRV could be a valid tool for predicting performance and improving interpretation of psychometric tests.
Key words: Sleep quality; mood states; self-esteem; performance.

Introduction

Electronic devices are now widely used to obtain objective measures of physical activity and movement patterns in studies of exercise and sport. Recent years have also seen the emergence of devices that permit ambulatory monitoring of psychological variables (e.g., mood states), thereby opening up new possibilities in the field of sports psychology (Schlicht, Ebner-Priemer, and Kanning, 2013). Studies of athletes using these devices are based on observation, but the methods of observation differ in terms of the level of participant involvement in the data collection (Portell, Anguera, Hernández-Mendo, and Jonson, 2015). Involvement for example, will be minimal when the device simply needs to be configured with the necessary settings, but it will be maximum when the study goal requires participants to self-report factors such as fatigue or pain. We use the term "automated observation" to refer to observational techniques that require minimum intervention from the participant.

In competition situations, methodological approaches based on automated observation are essential for analyzing psychological factors associated with the acquisition of skills aimed at optimizing performance (Buceta, 1998). Heart rate (HR) is one of the most widely used measures for this purpose in psychophysiological research, and it has been associated with numerous psychological variables (e.g., Draper, Jones, Fryer, Hodgson, and Blackwell, 2010; Fernandez-Fernandez et al., 2015). Recent years, however, have also witnessed a growing interest in HR variability (HRV), whose use in automated observation has been greatly facilitated by technological advances.

HR is typically measured as the number of heart beats within a predefined time (e.g., 1 minute). HRV, by contrast, refers to variations (measured in milliseconds) in the time interval between successive heart beats. HRV monitoring is a non-invasive tool for analyzing activity in the sympathetic and parasympathetic divisions of the autonomic nervous system. Predominant parasympathetic activity, for example, leads to a reduction in HR that returns or keeps the body in a state of rest following a stressful stimulus (e.g., physical activity, anxiety). Predominant sympathetic activation, by contrast, leads to an increase in HR that prepares the body for a situation of physical and/or psychological stress (Billman, 2011).

Most studies of HRV in the field of sport have analyzed HRV responses to different training stimuli with the ultimate aim of maximizing training effectiveness and benefits. Some authors, for example, have shown how HRV is a use-

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ful tool for maximizing adaptive responses and prescribing daily exercise (Kiviniemi, Hautala, Kinnunen, and Tulppo, 2007; Pichot et al., 2000; Plews, Laursen, Kilding, and Buchheit, 2012, 2014), while others have shown how HRV is influenced by training volume and intensity (Cottin et al., 2004; Kaikkonen, Hynynen, Mann, Rusko, and Nummela, 2010). HRV has also been linked to performance (Nummela, Hynynen, Kaikkonen, and Rusko, 2010) and overtraining (Hedelin, Wiklund, Bjerle, and Henriksson-Larsén, 2000) in endurance sports. Research on HRV has led to the development of HRV interpretation models that can help to adapt training loads to individual needs (Buchheit, 2014).

Given that HRV depends on the modulation of the autonomic nervous system, which has obvious implications in terms of emotional states, some authors have analyzed links between HRV and psychological aspects that can affect sports performance, such as anxiety (Cervantes, Rodas, and Capdevila, 2009; Morales et al., 2013) and a poor sleep quality, which can be predictors of a chronic fatigue syndrome (Burton et al. 2010; Plews et al. 2012). In the case of anxiety, HRV has been found to be susceptible to changes in anxiety levels in precompetition situations. Although individual differences must be taken into account to improve the accuracy of HRV measurements (Hautala et al., 2006), several authors have highlighted the potential of HRV monitoring as a rapid and effective tool for evaluating stress in competition situations (Thompson, Swain, Branch, Spina, and Grieco, 2015).

Other recent studies have analyzed the role of self-esteem in competition outcomes and highlighted the importance of evaluating feelings of self-worth in studies of sports psychology (Molina, Chorot, Valiente, and Sandín, 2014). Self-esteem is a personality trait defined by Rosenberg (1965) as a favorable or unfavorable attitude towards the self. Several authors have reported a negative association between self-esteem and emotional states such as anxiety (Coudevylle, Gernigon, and Ginis, 2011). However, while considerable work has been done on analyzing associations between self-esteem and academic performance (Esteban-Cornejo, Tejero-Gonzalez, Sallis, and Veiga, 2014), relatively little is known about how it affects performance in sport.

Sánchez et al. (2013), on analyzing the relationship between mood profiles and HRV in elite athletes, identified associations between numerous frequency-domain parameters and the fatigue and vigor domains of the Profile of Mood States (POMS) scale, which is widely used to predict performance in the field of sports psychology (Beedie, Terry, and Lane, 2008). Weinstein et al. (2007), in turn, found reduced parasympathetic activity to be a predictor of negative mood after exercise withdrawal. Despite these findings, data on the association between physiological correlates of HRV and psychological variables are contradictory.

Aside from the scarcity of studies analyzing HRV from a psychophysiological perspective, it is difficult to compare findings reported to date due to the variety of techniques that have been used to measure HRV (Task Force, 1996) and methodological differences in study design (Buchheit, 2014). More studies analyzing the links between HRV and psychological factors that affect sports performance in different populations are needed. To analyze the potential of HRV monitoring in young athletes, we pursued two objectives. The first was to analyze the association between HRV and three psychological correlates of performance: mood, self-esteem, and sleep quality, and the second was to analyze the association between these variables and performance. Such studies are essential if HRV is to be effectively used as a monitoring tool in the field of sport.

Method

Participants

The sample was composed of nine young swimmers with a mean ± *SD* age of 11.7 ± 1.4 years from the Redeco Swimming School in Wroclaw, Poland. There were seven girls (11.5 ± 1.5 years) and two boys (11.5 ± 2.1 years). The sample was structured base on purpose sampling strategy, using as criteria age and training method to homogenize the sample. The children trained from 7 a.m. to 8 a.m. every day, except at weekends, and most of them participated regularly in regional and provincial championships.

Instruments

The following instruments were used for the study:

The Polish version of the POMS scale developed by McNair, Loor, and Droppleman (1971) (Dudek and Koniarek, 1987). The short 6-item version of the scale (Cronbach α = .70) was used. The POMS scale evaluates 6 mood states: anxiety, depression, confusion, tension, vigor, and fatigue. Vigor is the only factor that is scored positively, i.e., a higher score in this domain indicates a better mood state. Each of the 6 states is scored using a Likert-type scale ranging from 0 (not at all) to 4 (extremely). We analyzed direct scores, and used the total score to determine total mood disturbance. This score is calculated by subtracting the score for vigor from the sum of scores for the other factors. High total mood disturbance scores reflect mood disturbances, while low scores indicate optimal mood states.

The Sleep Quality Scale of the Recovery-stress Questionnaire for Athletes (RESTQ-Sport) (Kellmann and Kallus, 2001), translated into Polish. This scale is scored on a 7-point Likert scale according to the respondent's level of agreement with each item (n = 4). Individual item scores are rated negatively, i.e., they are subtracted from the overall score.

The Rosenberg Self-Esteem Scale. This scale (Cronbach alpha = .81) was originally designed by Rosenberg (1965) to evaluate self-esteem in adolescents. It is composed of 10 items that measure feelings of self-worth and self-acceptance. Half of the items are related to positive feelings while the other half are related to negative feelings. They are scored using a Likert-type scale ranging from 1 (strongly disagree) to 4 (strongly agree). The total possible score therefore lies between 10 and 40. We used the validated Polish version of the scale (Dzwnokowska, Lachowicz-Tabaczek, and Łaguna, 2008).

Polar heart rate monitoring sports watch RS800CX and a Polar WearLink W.I.N.D transmitter with an elastic strap (Polar Electro Oy). This device has been used to monitor HRV in numerous studies (Plews et al., 2012, 2014; Quintana, Guastella, Outhred, Hickie, and Kemp, 2012).

BreathPacer. This is a mobile phone app used to control the participants' respiratory rate (RR) during the recording of RR intervals. It can be programmed with a predefined breathing rate and even duration of inhale and exhale phases. It comes with a timer.

Procedure

The study was conducted in accordance with the Declaration of Helsinki (WMA 2000, Bošnjak 2001, Tyebkhan 2003), which establishes the key ethical principles for research involving humans. We prepared a letter describing the study objectives and procedures for the children's parents or legal guardians and their coach, who was present during all stages of data collection. We also organized a talk for interested parents/guardians. The participants voluntarily agreed to take part in the study, and informed consent was obtained in all cases. The study was approved by the ethics committee at the University of Malaga (243, CEUMA register no. 18-2015-H).

The study data were collected every Friday for 3 weeks by the research team with the help of the children's swimming coach. The members of the team attended the training sessions for 3 days before the start of the study to become familiar with the swimmers. On the last day of each week's training program, the children participated in a mock competition consisting of a 200-m freestyle event. Every Friday, once they had completed their warm-up exercises, the children were given the POMS Scale, the Rosenberg Self-Esteem Scale, and the Sleep Quality Scale to complete. They were not asked to start until the research team was confident that they had understood the instructions and that their answers would be based on their emotions at the time. This process was supervised by a native Polish speaker.

After completing the questionnaires, each participant went to the medical room for HRV monitoring. For this, they lay in a supine position and followed a 0.2-Hz breathing pattern guided by the BreathPacer app according to established recommendations (Task Force, 1996). They then returned to the swimming pool (25-m) to complete the 200-m freestyle event, with a wall push-off. Their times were recorded by their coach using a manual stopwatch and then noted down.

Data processing and statistical analysis

Kubios HRV analysis software was used to correct errors and analyze RR intervals. This program can be used to calculate time-domain, frequency-domain, and non-linear parameters. For each analysis, the first and the last minute of each recording were excluded (Task Force, 1996). The frequency bands were adjusted to recommended values, as follows: 0.15-0.40 Hz for high frequency (HF), 0.04-0.15 Hz for low frequency (LF), and 0.00-0.04 Hz for very low frequency (VLF) (Task Force, 1996). Kubios HRV has been recognized as a valid tool for analyzing HRV in several scientific settings in recent years (Johnsen Lind, Helge Johnsen, Hill, Sollers Iii, and Thayer, 2011; Tarvainen, Niskanen, Lipponen, Ranta-Aho, and Karjalainen, 2014).

The Polar® RS800CX sports watch was programmed to analyze HR at a sampling frequency of 1000 Hz. Again, both the first and last minute of each recording were excluded from the analyses (Task Force, 1996). At least 256 successive RR intervals were analyzed per participant and session. In total, 6912 RR intervals were processed for the study. HRV data were transformed to natural logs (Ln) to reduce bias. Associations between physiological and psychological variables were analyzed in SPSS (v. 21 OS-X). The Pearson correlation test was used to study correlations between HRV and self-esteem, sleep quality, and mood state and also between performance (time taken to complete the 200-m freestyle event) and both HRV parameters and psychological variables.

Results

Table 1 shows the correlations between HRV parameters and POMS factors. There was an inverse correlation between parasympathetic activity (Ln HF) and two negative mood states: anxiety ($p < .01$) and confusion ($p < .05$). Ln HF was also negatively correlated with total POMS score. Ln VLF, which is associated with sympathetic activity, was positively correlated with anxiety and negatively correlated with vigor ($p < .05$). No significant correlations were found between any of the HRV parameters and either self-esteem or sleep quality.

Table 1. Pearson correlations between heart rate variability parameters and Profile of Mood States (POMS) factors.

		Sleep Quality	Self-Esteem	Anxiety	Depression	Confusion	Tension	Vigor	Fatigue	Total POMS score
Time domain	Ln rMSSD	.42	.68	- .06	- .20	- .06	.24	- .03	.18	.05
	Ln pNN50	.40	.76	- .03	- .14	- .07	.15	.14	- .07	- .07
Non-linear	Ln SD1	.42	.68	- .06	-.20	- .06	.24	- .03	.18	.05
Frequency domain	Ln HF	.88	.13	- .55**	- .41	- .53**	.12	.04	- .04	- .42*
	Ln VLF	.72	.15	.49*	.42	.39	- .08	- .45*	- .14	.37

** $p < .01$; * $p < .05$ (significant correlation levels). Ln rMSSD: natural logarithm of the mean squared difference of successive respiratory rate [RR] intervals; Ln SD1: natural logarithm of standard deviation of instantaneous beat-to-beat RR interval variability measured using Poincaré plots; Ln pNN50: natural logarithm of percentage of successive RR intervals that differ by more than 50 ms; Ln HF: natural logarithm of high-frequency component (0.15-0.40Hz); Ln VLF: natural logarithm of very low frequency proportion (0.003-0.04 Hz).

Table 2 shows the correlations between parasympathetic activity and performance in the 200-m freestyle event. The results show a negative correlation between the time-domain parameters Ln rMSSD and Ln pNN50 and performance. A similar negative correlation was found for the non-linear parameter Ln SD1. No significant correlations were found between any of the psychological variables analyzed and performance.

Table 2. Pearson correlations between performance in 200-m freestyle event and heart rate variability indicators related to parasympathetic activity.

	Time domain		Non-linear	Frequency domain
	Ln rMSSD	Ln pNN50	Ln SD1	Ln HF
Performance	- .45*	- .46*	- .44*	.28

* $p < .05$ (significant correlation levels). Ln rMSSD: natural logarithm of the mean squared difference of successive respiratory rate [RR] intervals; Ln SD1: natural logarithm of standard deviation of instantaneous beat-to-beat RR interval variability measured using Poincaré plots; Ln pNN50: natural logarithm of percentage of successive RR intervals that differ by more than 50 ms; Ln HF: natural logarithm of high-frequency component (0.15-0.40Hz).

Discussion

The aim of this study was to explore the potential of HRV monitoring for guiding the training of young athletes and shows a sport psychological application namely automated observation. To this end, we analyzed correlations between HRV parameters and performance in a 200-m freestyle event and different psychological determinants of performance. Our findings suggest that parasympathetic HRV parameters, i.e., measures related to rest and recovery, could be predictive of performance, while frequency-domain parameters might be more adequate for evaluating negative mood states.

This last finding is consistent with reports that HRV is a predictor of negative mood symptoms in athletes (Weinstein, Deuster, and Kop, 2007). No significant correlations were found between HRV parameters and fatigue. This result is in contrast to previous research that detected negative correlations between fatigue and parasympathetic indices (Moreno, Parrado, and Capdevila, 2013). Our findings for vigor, however, are consistent with previous research, as we found it to be negatively correlated with sympathetic activity.

Similarly to Cervantes et al. (2009), we observed an inverse correlation between anxiety and Ln HF, associated with parasympathetic activity, and a positive correlation between anxiety and Ln VLF, associated with sympathetic activity. Although the data suggest that HRV could help to detect altered mood states, it should not be forgotten that mood may also be influenced by factors unrelated to training. It is thus important that all individual results are subsequently analyzed by the training team.

Our study is among the first to analyze self-esteem in relation to HRV. Self-esteem is considered to be an important factor in young athletes (Bresciani et al., 2010; Esteban-Cornejo et al., 2014), and has been linked to performance (Molina et al., 2014), anxiety, and psychological factors (Coudevylle et al., 2011). In our group of young swimmers, we detected no correlations between self-esteem and either performance or HRV. Our findings for sleep quality were also non-significant. HRV monitoring would therefore not appear to be of value for detecting sleep disturbances or altered self-esteem, indicating the need to continue to use psychometric questionnaires to analyze how these aspects influence the performance of young athletes.

Parasympathetic activity parameters (Ln rMSSD, Ln pNN50, and Ln SD1) were negatively correlated with performance in the 200-m freestyle event. It should be noted that better performance (i.e., shorter times) would correspond to higher vagal activity values. Other authors have reported similar results for endurance sports (Buchheit et al., 2010; Garet et al., 2004). Nummela et al. (2010) observed that changes in maximum velocity reached on a treadmill by sedentary individuals after a period of training were consistent with changes in parasympathetic indices. Our study suggests that monitoring vagal activity–related variables could be useful for predicting performance in young athletes throughout the different stages of their development. Also, this work shows the potential of complementing conventional assessments of psychological variables with automated observation techniques.

Future studies should continue to analyze associations between psychological variables related to performance and HRV in young athletes. Access to effective tools for monitoring training during these important stages of an athlete's life is essential for guiding their development. The main limitation of our study was the small sample size, as we were unable to investigate cause-effect associations. Longitudinal studies are needed to analyze how variables change over different training periods, and it would also be interesting to analyze larger samples to test for sex-related differences and help guide individualized training plans. In these studies, it would be advisable to complement the physiological assess, based in automated observation method, with psychological constructs according to the criteria used for the day-to-day living research (Portell, Anguera, Hernández-Mendo, and Jonsson, 2015; Schlicht, Ebner-Priemer, and Kanning, 2013).

In conclusion, our study has revealed relationships between HRV parameters, mood states, and performance. As suggested by previous studies, HRV monitoring for 5 minutes in athletes at rest could be the most suitable non-invasive method for routinely assessing individual adaptations to training programs (Buchheit, 2014; Plews et al., 2012; Plews, Laursen, Kilding, and Buchheit, 2013; Moreno et al., 2013). Daily monitoring of indices that show how the autonomic nervous system regulates the cardiovascular system could help to predict the performance of athletes and also help to interpret psychometric questionnaire scores. Notwithstanding, authors such as Buchheit (2014) have suggested that psychometric tests will continue to be necessary given the complex and widely varied factors that can influence HRV (Billman, 2011).

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