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Analysis of internal and external load in elite Chilean skydivers during a competition
Análisis de la carga interna y externa en paracaidistas chilenos de élite durante una competencia

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Abstract. In skydiving, the monitoring of external and internal load is essential to establish energy demands. The objective of the study was to analyze the internal and external load performed by the Chilean national skydiving team during a national championship. A non-experimental, cross-sectional and descriptive study was carried out with the participation of six Chilean elite male skydivers (32.0 ± 3.2 years). Body composition was assessed through electrical bioimpedance (BIA); the internal load was analyzed from heart rate monitoring, and the external load was evaluated from accelerometry. The results showed that the skydivers had a fat-free mass of 61.3 ± 4.5 kg (representing 80.1 ± 2.3%), while the fat mass was 15.3 ± 2.5 kg (equivalent to 19.9 ± 2.3%). Their muscle mass measured 34.8 ± 2.8 kg (accounting for 45.5 ± 1.5%). Additionally, the skydivers engaged in 76.4 ± 13.1 minutes of moderate to vigorous physical activity per day, with a daily step count of 11.040 ± 2,202. The average heart rate during the competition was 104.0 ± 14.0 bpm. In conclusion, the physical activity undertaken by the skydivers during the competition primarily fell within the light to moderate intensity range, highlighting the sport's technical emphasis over its physical demands
Keywords: Energy expenditure, heart rate monitoring, accelerometry, exercise nutrition physiology

Resumen. En el paracaidismo, el monitoreo de la carga externa e interna es esencial para establecer las demandas de energía. El objetivo del estudio fue analizar la carga interna y externa realizada por la selección nacional de paracaidismo de Chile durante un campeonato nacional. Se realizó un estudio no experimental, transversal y descriptivo con la participación de seis paracaidistas chilenos de élite masculino (32,0 ± 3,2 años). La composición corporal se evaluó mediante bioimpedancia eléctrica (BIA); La carga interna se analizó a partir de la monitorización de la frecuencia cardíaca y la carga externa a partir de la acelerometría. Los resultados mostraron que los paracaidistas tenían una masa libre de grasa de 61,3 ± 4,5 kg (lo que representaba 80,1 ± 2,3%), mientras que la masa grasa era de 15,3 ± 2,5 kg (equivalente a 19,9 ± 2,3%). Su masa muscular medía 34,8 ± 2,8 kg (lo que representaba 45,5 ± 1,5%). Además, los paracaidistas realizaron entre 76,4 ± 13,1 minutos de actividad física moderada a vigorosa al día, con un recuento de pasos diarios de 11,040 ± 2.202. La frecuencia cardíaca promedio durante la competencia fue de 104.0 ± 14.0 lpm. En conclusión, la actividad física realizada por los paracaidistas durante la competencia se ubicó principalmente dentro del rango de intensidad ligera a moderada, lo que destaca el énfasis técnico del deporte por encima de sus exigencias físicas
Palabras clave: Gasto energético, monitorización de la frecuencia cardíaca, acelerometría, fisiología de la nutrición del ejercicio

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Introduction

In recent years, skydiving has gained a lot of attention, increasing the number of people who practice it both recreationally and competitively (Barthel et al., 2023). Although the prevalence of injuries in this sport is low, skydiving is considered high-risk because its practice can cause serious injuries (Mohamed et al., 2015). Several studies have shown that excessive training load can influence sports injuries (Saragiotto et al., 2014), increasing the risk of serious events in skydiving, and it has also been seen that there are few studies that address the intensity of physical activity performed during its practice and especially during the development of the competitions of this discipline. This study seeks to address this aspect.

When thinking about the discipline of parachuting it is natural to associate it with the possibility of serious and even fatal accidents; however, many of the accidents that occur are mainly due to human error (Zakowski et al., 2019). In skydiving, as well as the importance of the aspects related to the flying technique, safety standards (before, during and after the jump), emergency procedures to be adopted in case of an equipment failure or human error, it is fundamental to bear in mind the management of some physiological effects, such as hypoxia which occurs at an altitude of approximately 3660 m (12,007 feet), which can result in drowsiness, and muscular and mental fatigue (Machado et al., 2022)

Currently, one of the unique characteristics in sport is that the energy requirements of training and competition increase the total daily energy expenditure (TDEE) beyond those of the general population (Westerterp, 2013). Energy requirements can vary considerably depending on the type, intensity, and duration of exercise, but sustained levels of energy expenditure (EE) can range from 5,000 to 8,000 kcal/day (Westerterp et al., 1986; Westerterp, 2001). Considering that athletes expend up to 75% of their total daily energy expenditure during exercise (Westerterp, 2013), quantifying energy needs during training and competition, special attention is required to identify these aspects to program nutritional strategies for competition (Koehler & Drenowatz, 2017). Energy expenditure is reflected through physical activity, the thermic effect of food, and basal metabolic rate (Dávalos et al, 2017). Although physical activity refers to any body movement produced by skeletal muscles that leads to energy expenditure (Hallal et al., 2013), it is relevant to consider the qualitative assessment of this based on the analysis of the intensity developed. Generally, energy requirements can be assessed based on resting metabolic rate (RMR) (Herrera-Amante et al., 2021; Jamin et al., 2018), which is the amount of energy expended at rest by a fasting individual in a thermoneutral environment, representing 60% to 70% of total energy expenditure in healthy normal-weight adults, and varying percentages in athletes (Marra et al., 2016). Sustainable energy balance is one of the main goals of nutritional support for athletes training to increase their exercise capacity (Loucks, 2004). For equilibrium to be achieved and maintained, the energy consumption of food must correspond to the current energy demand. Otherwise, the energy balance can be disturbed and can lead to unfavorable changes in athletes' body mass, composition, and function, as well as reduced exercise capacity (Arieli & Constantini, 2012). This factor is especially relevant since in skydiving competition, athletes must maintain similar body composition profiles that allow optimal maneuverability in the air (Yáñez-Sepúlveda et al., 2021). Evidence has shown that when more energy is consumed than expended, a positive energy balance is generated, the surplus energy is converted into fat tissue that increases body mass, which can affect motor skills and performance when developing shapes or at the time of developing precision landing tests. However, an excessive energy intake does not mean that the demand for nutritional substances for optimal functioning is met. When a diet is rich in energy, but poor in certain minerals, vitamins, or proteins, qualitative malnutrition can develop (Frączek et al., 2019) that affects athletic performance. It is at this point where the assessment of the intensity of physical activity plays a major role because it allows us to guide nutritional strategies to avoid caloric deficit or excess in skydivers while competing. Therefore, planning nutritional strategies that emphasize optimal exercise capacity should begin with determining an individual's energy needs by estimating their daily energy expenditure (Fraczek et al., 2019). It has been seen that higher energy expenditure is required for sports training and competition (Ekelund, 2002). To maintain a good energy balance, to achieve and maintain adequate body weight, body composition, and glycogen storage, athletes need to consume enough food to match their total daily energy expenditure or energy needs (Hawley, 1995). Energy expenditure is modulated by intensity, volume and/or time interval as a whole, as stated by three studies (Bahr et al., 2005; Braun et al., 2005 and Scott et al., 2006) in which they analyzed the variables that make up the different training methods. Kelleher et al. (2010) found no differences for the agonist/antagonist method, which is considered intense for consecutively performing two exercises and increasing mechanical work, similar to circuit training, however, observed a 25% increase in electromyography activity and suggested that the increased recruitment of motor units theoretically required higher caloric expenditure (DeGroot et al, 1998).

Most of the equations commonly used to estimate RMR in the general population (Harris and Benedict (1918), Schofield (1985), FAO/WHO/UNU (1985), Mifflin (1990) and Owen (1987)) have been developed based on minimally active or sedentary individuals. Considering the different levels of physical activity and body composition (i.e., higher fat-free mass and body cell mass with lower fat mass) relative to the general population (Ribeyre et al., 2000), the equation used to estimate RMR in the general population may not be appropriate for athletes. From this, some specific predictive equations have been developed to estimate the RMR for athletes (Melby et al., 1990: Poehlman et al., 1988; Ribeyre et al., 2000), and yet they have some limitations.

In any nutritional approach, intake must be adapted to energy and nutritional requirements (Gündüz, 2016). To do this, it is essential to know as accurately as possible to estimate TDEE (Cruz 2015). There are several methods for measuring energy expenditure, including direct calorimetry, indirect calorimetry, the doubly labeled water (DLW) method, heart rate monitoring, a kinematic method, and a chronometric-tabular method using questionnaires, diaries, and physical activity tables (Ainslie et al., 2003; Lipert and Jegier, 2009; Strath et al., 2013). The methods differ both in convenience and in the reliability and precision of the measurements. The most reliable are thought to be indirect calorimetry, DLW, and indirect calorimetry (Ainslie et al., 2003). Even so, the inherent weaknesses and high costs of the methods prevent them from being widely used in studies on training energy expenditure or the TDEE of athletes (Frączek et al., 2019)

On the other hand, accelerometry is a recent method used to quantify workload in team sports. An increasing number of studies support the practical implementation of accelerometry monitoring to regulate and optimize training schemes (Gómez-Carmona et al., 2020). Several previous studies have validated wrist accelerometry derivatives against gold standard measures of energy expenditure, such as the Doubly Labeled Water (DLW) method (Van Hees, 2011) and indirect calorimetry from respiratory gas analysis (Esliger 2011). However, the high cost of DLW has precluded such work in large population samples, and the nature of the measurement only allows exploration of the total volume of activity, rather than the underlying intensity time series (White et al., 2016). Accelerometry is supposed to be the most objective technique for recording gross body movements (Ekelund, 2011). Previous studies have compared the assessment of physical activity using the accelerometer versus measurement of physical activity in questionnaires estimated using the DLW technique. Physical activity assessed by accelerometer was a significant predictor (Hallal et al., 2013), according to the literature reviewed (Ekelund et al., 2001), as in (Hoos et al., 2003), and finally, in studies with children and adolescents (Johnson et al., 1998), where positive correlations were also found.

Considering the background provided, the objective of this study was to identify the level and intensity of physical activity performed by a team of high-performance skydivers during a national championship in Chile.

Methodology

Design and type of study

Non-experimental, cross-sectional and descriptive study.

Participants

Six male elite skydivers belonging to the Chilean national team, aged between 27-37 years (32.0 ± 3.2 years), participated in this study. None of the athletes had a medical history. The study was conducted over five consecutive days during the national sports skydiving championship in Chile.

Measurement

Body composition with bioelectrical impedance analysis (BIA).

Three evaluations were conducted for the study, and the median was used for result analysis. Participants were convened to a meeting the day before the competition. During the competition week, a university nutritionist adjusted the nutritional requirements and hydration. Measurements were obtained by personnel trained in BIA assessment. An INBODY® model S10 octopolar bioimpedance device was used, a technology validated in this population (Aandstat et al., 2014), allowing estimation of body composition components and hydration status. The evaluation procedures described by Yáñez-Sepúlveda et al., (2021) in a previous study conducted with paratroopers were used.

Intensity of physical activity performed

Participants received an ACTIGRAPH® model GT3X accelerometer. An instruction sheet was given to participants containing a brief description of the device, details on how to use it, and contact information for the researchers. This instruction sheet also includes a journal for the devices. Se instruyó a los participantes a observar si no llevaban el monitor para cualquier período de una hora 0,1 durante el día. Subjects wore the monitor Monday through Friday and were encouraged to wear it all day, except in the shower, bath or swim. Primarily Saturday morning, field researchers visited the participants' home to collect the monitor and journal, which provided notes on the device's use. As a result, all athletes recorded the composite accelerometer data on five consecutive days (Monday, Tuesday, Wednesday, Thursday, and Friday). Technical details of the device, as well as data on its validity, are available in other studies (Esliger et al 2011). The device was placed on the right side of the hip. A sampling rate of 100Hz was used for the programming of the device, with a normal filter, the time was set at 60 seconds and the data were analyzed using Actilife 6.0 software (Miqueles et al., 2017). For the purposes of this analysis, physical activity variables were expressed as mean counts per minute (MPC), as an indicator of the intensity of average daily physical activity, and the time spent in the process. actividad física moderada vigorosa. Para To estimate the intensities, the equations of Sazaki et al. (2011) were used, considering the following cut-off points: light <2690cpm, moderate 2691 to 6166cpm, vigorous 6167 to 9642cpm and very vigorous >9643cpm.

Heart rate monitoring during competition

To monitor heart rate (HR), POLAR® H10 bands were used that were synchronized with the accelerometers via Bluetooth through the Actilife 6.0 program. Resting HR, active HR during competition, and delta HR (active HR-resting HR) were obtained.

Ethical Considerations

The study protocol was in accordance with the ethical guidelines of the Declaration of Helsinki (World Medical Association, 2013). Prior to the evaluations, the purpose of the study was reported and all the procedures to be carried out were explained. Participants signed an informed consent form prior to the development of the study. The study data were coded anonymously and stored on the principal investigator's personal computer, which had a password and fingerprint. This study was approved by the scientific committee of the Chilean Air Force Sports Federation (code: 1-2018).

Data analysis

The statistical data were analyzed with the statistical program JAMOVI® version 2.3.21 for Windows. The mean and standard deviation (±) statistics plus the minimum and maximum value were considered to describe the study variables.

Results

Table 1 shows the results, showing a professional experience of 8.7 ± 3.3 years with an average number of jumps of 1.069 ± 362. Height was 1.72 ± 0.05m, and body mass was 76.6 ± 6.1kg; The mean BMI was 26.0 ± 2.0 kg/m2, the fat-free mass was 61.3 ± 4.5 kg (80.1 ± 2.3%), while the fat mass was 15.3 ± 2.5 kg (19.9 ± 2.3%), the mean muscle mass was 34.8 ± 2.8 kg (45.5 ± 1.5%). The results of the other components of body composition are observed.

Table 2 shows the accelerometry results. The energy expenditure in calories during the 5 days was an average a daily consumption of 523.3 ±80.2kcal and an hourly value of 26.4 ± 3.8kcal, the METs were 1.2 ± 0.1 per hour. Resting heart rate was 73.0 ± 2.0bpm with a maximum heart rate of 104.0 ± 14.0bpm and a delta of 32.0 ± 14.0 ppm, these results are consistent with light and moderate physical activity intensities. The number of steps per day was number 11.040 ± 2.202.

Table 1.
Basic characteristics and anthropometric measurements of the group of skydivers

Variable	Mean	Std. Deviation
Years of professional experience	8.7	3.3
Number of jumps	1.069	362
Size (m)	1.72	0.05
Body mass (kg)	76.6	6.1
Body mass index (weight/m2)	26.0	2.0
Fat-free mass (kg)	61.3	4.5
Fat-free mass (%)	80.1	2.3
Body fat (kg)	15.3	2.5
Body fat (%)	19.9	2.3
Muscular mass (kg)	34.8	2.8
Muscular mass (%)	45.5	1.5
Body Cell Mass	40.6	3.1
Visceral fat area	74.1	10.1
Bone mineral content (kg)	3.4	0.3
Segmented lean mass in right arm (kg)	5.3	4.9
Segmented lean mass in left arm (kg)	3.5	0.3
Segmented lean mass in trunk (kg)	27.2	2.0
Segmented lean mass in right leg (kg)	9.2	0.7
Lean mass in left leg (kg)	9.1	0.7

Table 2.
Energy expenditure and heart rate

Variable	Media		DE	Min	Max
Calories Per Day	523.3	±	80.2	451.0	661.7
Calories Per Hour	26.4	±	3.8	22.5	33.1
METs	1.2	±	0.1	1.1	1.2
Steps Per Minute	8	±	1.5	6	10
Steps Per Hour	460	±	92	354	576
Day Steps	11.040	±	2.202	8.496	13.824
Minimum Heart Rate (bpm)	73.0	±	2.0	70.0	74.0
Active Heart Rate (bpm)	104.0	±	14.0	9.0	128.0
Heart Rate Delta (bpm)	32.0	±	14.0	19.0	57.0

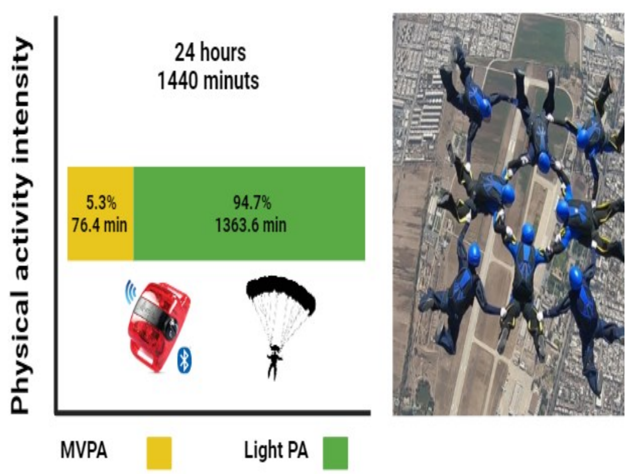

Figure 1. Level of daily physical activity in the group of skydivers during the championships. MVPA: moderate to vigorous physical activity; PA: physical activity.

Figure 1, showed that the skydivers spent 5.3% of the day, which equaled 76.4 minutes in moderate to vigorous physical activity (MVPA).

Discussion

The results of this study show that the professional skydivers of the Chilean national team performed mainly light and moderate physical activity intensities during the development of the championship, it was also observed that they completed over 10,000 steps per day. It is important to note that during this stage the athletes were competing, so the workloads were less than the usual training they do for their physical preparation, despite this, the athletes performed more than one hour of moderate intensity PA per day (62.20±13.17 min x day). It is relevant to consider that in this sport training should consider aerobic, strength and flexibility training (Deitrick et al., 1985). To the authors' knowledge, this is the first study to analyze the intensity of physical activity performed in elite skydivers during a championship, so there is little evidence in this sport discipline. Similar studies such as that of Frazeck et al., (2019) where they estimated the total daily energy expenditure (TDEE) in 30 Polish elite athletes (15 women and 15 men aged 20 to 34 years) who practice aerobic endurance sports and speed-strength sports, found mean TDEEs of significantly higher male athletes 3778.0 ± 657 kcal/24h for aerobic endurance athletes and 2970.4±345 kcal/24h for speed-strength athletes. The study revealed that the actual energy needs of individual athletes can vary over a wide range and may differ from the recommended energy intake (Frączek et al., 2019). In another study, Ellis et al., (2024) studied the total daily energy expenditure (TDEE) of elite tennis players. Using Actiheart activity monitors during a training period of 2 to 5 days, male players were analyzed for 26 days in men who had a TDEE of 4,708 ± 583 kcal/day and 46 days in women who reported a TDEE of 3,639 ± 305 kcal/day, presenting significant differences in favor of men. In another study, Brinkmans et al. (2024) evaluated total daily energy expenditure (TDEE) in professional female soccer players, finding a TDEE of 2882 ± 278 kcal/day.

On the other hand, Kaproi et al. (2024) analyzed the level of physical activity and energy expenditure of athletes who practice various sports daily. The research included 53 female athletes (43.39% elite and 56.61% non-elite) and 47 male athletes (40.42% elite and 59.57% non-elite) who competed in track and field, basketball, badminton, cricket, hockey, kabaddi, volleyball, and wrestling.

Results of the study according to the reports by sport highlight elite boxing women 4253.75 kcal/day versus non-elite 2391.70 kcal/day, and in elite men 4279.56 kcal/day versus non-elite 3243.23 kcal/day; in wrestling elite women 3632.56 kcal/day versus non-elite 2611.25 kcal/day, elite men 4636.29 kcal/day, versus non-elite 3129.86 kcal/day, and in total elite women had a TDEE of 3964.5 ± 423.84 versus non-elite 2854.6 ± 452.66 kcal/day, while elite men 4556.7 ± 591.48 kcal/day versus non-elite 3080.4 ± 489.06 kcal/day. As a result, it can be seen that the need for energy expenditure varies depending on the sport. For example, a single bout/round in wrestling and boxing lasts around 3 minutes. The intensity of athletes' effort and the frequency of physical activity are quite high during this time, so their energy consumption is very high (Kaproi et al., 2024).

Furthermore, it is essential to contextualize these findings within the unique demands of skydiving. Unlike traditional team sports, skydiving involves unique physiological stresses such as rapid altitude changes and the psychological impact of high-adrenaline activities (Meyer et al., 2015). These factors can significantly influence energy expenditure, suggesting that skydivers may require tailored nutritional strategies to accommodate the sporadic yet intense bursts of activity inherent to the sport. This underscores the need for sport-specific research to inform nutritional and training regimens that support the distinctive energy requirements of skydiving.

In a systematic review, Kim & Park (2023) reviewed the existing evidence on TDEE measured using the doubly labeled water (DLW) technique in football, basketball, and rugby players. The 13 studies included four rugby players, six football players, and three basketball players; Six of the 13 studies involved young players. The TDEE measured using the DLW method was 3,862.3 to 5,783.9 kcal/day for rugby, 2,859 to 3,586 kcal/day for football and 4,006 to 4,921 kcal/day for basketball players. These results show that collision sports players vary according to training or match load, body composition, and measurement period, therefore, individual approaches to nutritional prescriptions for these athletes should take into account different periods, anthropometric profiles, training, and game loads Kim and Park (2023). In another study by Costello et al. (2018) they measured TDEE using the double-labeled water (DLW) technique, it was significantly higher for collision activities than for non-collision activities (4542.5 ± 796.0 Kcal/day versus 4316.5 ± 810.8 kcal/day)

Some of the highest energy expenditures recorded in humans have been reported during high-volume training in collegiate swimmers (5593 kcal/day) (Trappe et al., 1997), in hikers during a trip across Australia (6321 kcal/day) (Hill and Davis, 2001), and among cyclists during Tour de France (7000-8500 kcal/day) (Westerterp, 1986). One of the sports with the most evidence available is athletes and based on the data available for athletes, it appears that young athletes expend approximately 2500-3500 kcal/day (Eisenmann and Wickel, 2007).

Clearly, there is a need for more detailed studies on energy balance in skydivers so that dietary recommendations can be made based on empirical data. This information has important implications because energy balance is necessary for optimal growth, maturation, health, and physical performance. It is suggested that future studies consider the assessment of energy demands from GPS, it would also be relevant to integrate the assessment of body composition with anthropometry and DXA, it is also suggested to develop studies comparing energy demands between precision and team competitions, finally it would be interesting to compare the bioenergetic demands in teams and their relationship with asymmetries in body composition among participants.

Limitations

Due to the access to this type of sport, the main limitation of the study is the sample size. Another important limitation is that because they were during a period of competition, the skydivers had a lower external load volume than usual, so future studies should consider measuring the load during the different phases of training.

Practical applications

Based on the results obtained in this study, it is suggested to consider the following aspects:

1. It is suggested to nutrition professionals to adjust the nutritional requirements in this sport considering the training schedule and the phase in which the athletes are.

2. Monitoring the intensity of physical activity through accelerometry provides valuable information for organising training loads and rests.

Conclusions

It is concluded that skydivers mainly develop light to moderate physical activity during the development of the championship, which allows to avoid physical overload. This study provides reference data for the programming of training and nutrition in this sport, an input that can be used by professionals to optimize sports performance.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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