Effect of training at moderate altitude on the technical and muscular performance in elite judokas

Application to the technical learning process

Efecto del entrenamiento en altitud moderada sobre el rendimiento técnico y muscular en judokas de élite

Aplicación al aprendizaje de la técnica

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Abbreviations and judo-specific words

Ashi-waza - leg techniques

CMJ - countermovement jump

COM - center of mass

FIO_2 - inspired fraction of oxygen

F-V - force-velocity relationship

F_0 - theoretical maximal force that can be produced at null velocity, calculated by an extrapolation of the intercept with the force-axis in a F-V relationship

Hajime - the signal for match start / restart

Hane-goshi - judo technique

Harai-goshi - judo technique

Hikite - sleeve pulling action

IHE - intermittent hypoxic exposure during rest

IHIT - intermittent hypoxic exposure combining IHE and IHT

IHT - intermittent hypoxic exposure during interval training sessions

Ippon - judo score equivalent to a full point

Ippon-seoi-nage - judo technique

JH - jump height

Judogi – judo suit

Kake - third phase of the technique that corresponds to the throwing action

Koshi-waza - hip techniques

Kumi-kata – grip

Kuzushi – first phase of the technique that corresponds to the unbalance

LHTH - 'live high-train high' hypoxic training strategy

LHTL - ‘live high-train low’ hypoxic training strategy

LHTLH - ‘live high-train low and high’ hypoxic training strategy

L_0 - maximal theoretical load, calculated by an extrapolation of the intercept with the load-axis in a load-velocity relationship

Mate - combat interruption signal

MPV - mean propulsive velocity

MV - mean velocity

Nage-komi - training method that consist in successive technique throws

Ne-waza - groundwork phase

Osoto-gari - judo technique

PB - barometric pressure

PIO_2 - inspired partial pressure of oxygen

P_{max} - theoretical maximal power ($P_{max} = F_0 \cdot V_0/4$)

PV - peak velocity

rep - repetition

RPE – rate of perceived exertion

RT - resistance training

RTH - resistance training under hypoxic conditions

RSH – repeated sprint ability training under hypoxic conditions

RWL - rapid weight loss

Seoi-nage - judo technique

S_{fv} - force-velocity relationship slope; lower-limb mechanical force-velocity profile

S_{fv}-OP - optimal F-V profile; the ideal profile that would maximize jump height for a given athlete

S_{lv} - load-velocity relationship slope

SJ - squat jump

SpO_2 - arterial oxygen saturation levels

Sutemi-waza - techniques that sacrifice personal balance to throw

Tori - person who throws

Te-waza - arm techniques

Tsukuri – second phase of the technique that corresponds to the entry and proper fitting of the body into the position taken just before throwing

Uchi-komi – training method that consist in successive repetitions of a technique

Uchi-mata - judo technique

Uke - person who is thrown

V_0 - theoretical maximal velocity under zero load, calculated by an extrapolation of the intercept with the velocity-axis in a F-V relationship or in a load-velocity relationship

Wazari - judo score equivalent to half point

1RM - 1 repetition maximum

Abstract / Resumen

The influence of resistance training under hypoxic conditions (RTH) on the development of strength and muscle mass is a research area of current interest. However, there is no consensus on the beneficial influence of hypoxic training conditions on muscle functional and physiological adaptations, especially when real altitude is used. Specifically, the influence of hypobaric hypoxia on power-oriented resistance training (RT) remains unexplored, as well as its effects on technical and physical adaptations in judokas, or the evolution of those effects on athletes after returning to sea level. Moreover, transference from physical improvements to technical performance in judo has not been examined before. Therefore, the main goal of this thesis was to analyze the effect of a power-oriented RT program at moderate altitude on the leg extension capacity, on the *ippon-seoi-nage* performance and on the relationship between them in elite judokas.

A longitudinal design, with intra- and inter-group measurements, was used to compare the effect of a lower-limb power-oriented RT at moderate altitude (hypobaric hypoxia) or sea level (normoxia) on leg extension capacity, on kinematic variables of the *ippon-seoi-nage* and on the relationship between them in elite judokas. Twenty-four male judokas from the Spanish Judo Training Center of Valencia, all international medalists, participated in this study. Participants were randomly assigned to a group that performed a 3-week training program at hypobaric hypoxia (at the High Performance Center of Sierra Nevada, 2320 m; HT; n = 13) or normoxia (at the Spanish Judo Training Center of Valencia, 15 m; NT; n = 11). Testing sessions were conducted under normoxic conditions at 4 time-points: pre-test (N1), post-test (N2), one and two weeks after training (N3 and N4, respectively). The HT undertook an additional testing session in acute hypoxia (H1) conditions immediately after the ascent to altitude. An additional intra-group design was

used to assess the effect of an acute exposure to moderate altitude on the same variables (N1 vs. H1). Testing sessions comprised 1) a body composition assessment that included anthropometrical and bioelectrical impedance analysis variables, 2) an incremental countermovement jump (CMJ) test to determine leg extension load-velocity and force-velocity profile and 3) an *ippon-seoi-nage* test to assess the kinematic variables transferred to the *uke* during this technique. The 3-week power-oriented training program applied included a physical conditioning session in the morning and a judo session in the afternoon, from Monday to Saturday morning. Physical conditioning training included 3 power-oriented RT sessions per week alternated with 3 metabolic sessions. The content of the physical conditioning sessions was designed and supervised by the research team, while judo sessions were designed by the coaches. Each power-oriented RT session included 1) a velocity-based training (4-6 sets of 6 CMJ with the load associated to a mean propulsive velocity (MPV) of 1.2 $m \cdot s^{-1}$ calculated in the pre-test, on Wednesdays and Fridays, and with the load associated to a MPV of 1.2 $m \cdot s^{-1}$ adjusted each Monday at the corresponding condition, with 4 minutes of rest) and a 2) contrast training (3-4 sets of 2 repetitions of a moderate to high-load RT exercise followed by 6 repetitions of *ippon-seoi-nage* throws at maximal intended velocity, with 4 minutes of rest).

Acute hypoxia caused small increases in leg extension peak velocity (PV) (3.67%; $p < 0.05$), while no changes in the kinematic variables of the *ippon-seoi-nage* were observed. *Ippon-seoi-nage* kinematic variables show a great individual reliability, which contrasts with the low reliability observed when the whole group is considered. The coefficient of variation ratio (H1/N1) of the time needed to reach the leg extension during the technique performance increased. There was a RT effect on the leg extension PV, jump height (JH) and maximal theoretical force (F_0, determined using mean values of force and velocity) ($p < 0.05$), both at moderate altitude and sea level. PV and JH also displayed a time × altitude interaction effect ($p < 0.05$). A detailed analysis of this interaction showed a higher magnitude of change in PV, JH and F_0 in HT than NT, which was achieved one week earlier (HT-N2 vs. NT-N3: 8.78 vs. 5.58% for PV; 8.20 vs. 1.41% for JH; 11.76 vs. 7.61% for F_0; $p < 0.05$). The force-velocity profile of both groups displayed important imbalances due to lower current values in F_0 ($p < 0.001$, $\eta^2_p = 0.889$) and higher values in maximal theoretical velocity (V_0) ($p < 0.001$, $\eta^2_p = 0.844$) compared with the optimal expected. Although no significant differences were found between the imbalances of both groups at all time-points, complementary results showed a trend for a moderate reduction of this imbalance from N1 to N2 in HT and from N1 to N3 in NT (-11.96% and -7.88%, respectively, $p < 0.10$). An altitude main effect was registered for *ippon-seoi-nage* variables ($p < 0.05$), with the HT displaying a 22.95% smaller increase in the acceleration of the leg extension phase than NT ($p = 0.03$) and an increase in the time to reach the horizontal position while a decrease was observed in NT (difference between HT and NT = 18.68%, $p = 0.003$). The training period did not induce any changes in anthropometrical and bioelectrical impedance analysis variables, nor did the altitude condition affect these variables ($p > 0.05$). There was no association between the leg extension mechanical variables and the acceleration or angular velocity transferred to the *uke*, nor did acute exposure to hypoxia or training at different altitude conditions affect this association.

These results show an increase in the leg extension capacity from the first exposure to altitude, which is in accordance with the literature. Later, after a power-oriented RT period, moderate altitude seems to increase and accelerate peak performance. A detailed analysis of the time × altitude interaction effect showed that HT achieved the highest leg extension PV and JH compared to NT and achieved it earlier (in N2 vs. N3) ($p < 0.05$). The technical performance variables did not show changes due to acute exposure to moderate altitude, while an impairment was observed after altitude training, due to a rise in the times and accelerations transferred to the uke. Changes in physical condition, together with changes in the space-time pattern of the technique induced by altitude exposure, confirm the need to adjust and stabilize the technique during and after an altitude training period in sports with complex technical skills. Finally, differences between individual and within-groups coefficient of variation confirm that each judoka adapts the technique to his characteristics, always performing it in the same way. Nevertheless, the absence of association between the leg extension capacity and *ippon-seoi-nage* performance could indicate that, at least in the sample studied, the legs implication during the *ippon-seoi-nage* was not sufficient according to the technical gold standard. Future studies are needed to further analyze the technique, the nature of the strength adaptations and its transference to the technical performance as consequence of hypoxic exposure and training.

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La influencia del entrenamiento de fuerza en condiciones de hipoxia (RTH) sobre el desarrollo de la fuerza y masa muscular se está convirtiendo en un área de investigación de gran interés. Sin embargo, no existe consenso sobre el efecto positivo del entrenamiento en hipoxia sobre las adaptaciones funcionales y fisiológicas, especialmente en el caso de la altitud real. Son escasos los estudios sobre la influencia de la hipoxia hipobárica en el entrenamiento orientado a la potencia muscular, así como sobre sus efectos en las adaptaciones técnicas y físicas de los judokas y la evolución de estos efectos después del regreso a nivel del mar. Además, la transferencia de las mejoras condicionales al rendimiento técnico nunca ha sido estudiada. Así, el objetivo principal de este estudio fue analizar el efecto de un programa de entrenamiento orientado a la potencia muscular en altitud moderada sobre la capacidad de extensión de piernas, el rendimiento del *ippon-seoi-nage* y la relación entre ambos en judokas de élite.

Se utilizó un diseño longitudinal, con medidas intra- e inter-grupo, para comparar el efecto de un entrenamiento orientado a la potencia de piernas en altitud moderada (hipoxia) o a nivel del mar (normoxia) sobre la capacidad de extensión de piernas, las variables cinemáticas del *ippon-seoi-nage* y la relación entre ambos en judokas de élite. Participaron en este estudio 24 judokas del Centro de Entrenamiento Nacional de Judo de Valencia, todos medallistas internacionales. Los participantes fueron aleatoriamente asignados a un grupo que realizaba un entrenamiento de tres semanas en hipoxia hipobárica (en el Centro de Alto Rendimiento de Sierra Nevada, 2320 m; HT; n = 13) o en normoxia (en el Centro de Entrenamiento Nacional de Judo de Valencia, 15 m; NT; n = 11). Los test se realizaron en normoxia en 4 momentos distintos: pre-test (N1), post-test (N2), una y dos semanas post-entrenamiento (N3 y N4, respectivamente). El HT realizó un test adicional en hipoxia aguda (H1), inmediatamente después del ascenso. Se usó un diseño intra-grupo adicional para analizar el efecto de la exposición aguda a la altitud moderada sobre las mismas variables (N1 vs. H1). Los tests incluían 1) un análisis de la composición corporal a través de antropometría y análisis de impedancia bioeléctrica, 2) un test incremental de countermovement jump (CMJ) para determinar el perfil fuerza-carga-velocidad en la extensión de piernas y 3) un test de *ippon-seoi-nage* para estudiar las variables cinemáticas transferidas al *uke* durante la ejecución de esta técnica. El programa de entrenamiento incluía una sesión de acondicionamiento físico por la mañana y una sesión de judo por la tarde, de lunes a sábado por la mañana. El programa de acondicionamiento físico incluía 3 sesiones semanales de entrenamiento orientado a la potencia muscular alternadas con 3 sesiones metabólicas. El contenido del programa de acondicionamiento físico fue diseñado y supervisado por el equipo de investigación, mientras que las sesiones de judo fueron diseñadas por los entrenadores. Cada sesión de entrenamiento orientado a la potencia muscular incluía dos partes: 1) entrenamiento basado en la velocidad (4-6 series de 6 CMJ, los miércoles y viernes con una carga asociada a 1.2 $m \cdot s^{-1}$ de la velocidad media propulsiva (MPV) del pre-test, y cada lunes con una carga asociada a 1.2 $m \cdot s^{-1}$ de la MPV ajustada a cada condición en ese momento, con 4 minutos de descanso) y 2) entrenamiento de contraste (3-4 series de 2 repeticiones de un ejercicio de fuerza con una carga moderada-alta seguido de 6 proyecciones de *ippon-seoi-nage* ejecutadas a máxima velocidad, con 4 minutos de descanso).

La exposición aguda a la hipoxia causó pequeños incrementos en la velocidad pico (PV) de extensión de piernas (3.67%; $p < 0.05$), mientras que no se verificaron cambios en las variables cinemáticas del *ippon-seoi-nage*. Las variables cinemáticas del *ippon-seoi-nage* mostraron una gran fiabilidad individual que contrasta con la baja fiabilidad grupal observada. Finalmente, la ratio del coeficiente de variación (H1/N1) del tiempo necesario para alcanzar la extensión de piernas durante la ejecución de la técnica aumentó. Se ha verificado un efecto del entrenamiento orientado a la potencia en la PV, altura de salto (JH) y fuerza máxima teórica (F_0, calculada a partir de valores medios de fuerza y velocidad) de extensión de piernas ($p < 0.05$), en altitud moderada y a nivel del mar. La PV y la JH mostraron un efecto de interacción momento × altitud ($p < 0.05$). El análisis pormenorizado de esta interacción mostró una mayor magnitud de cambio en la PV, JH y F_0 del HT que del NT y que el HT la ha alcanzado una semana antes (HT-N2 vs. NT-N3: 8.78 vs. 5.58% para la PV; 8.20 vs. 1.41% para la JH; 11.76 vs. 7.61% para la F_0; $p < 0.05$). Se han observado importantes desequilibrios en el perfil de fuerza-velocidad de ambos grupos, causados por valores actuales de F_0 bajos ($p < 0.001$, η^2_p = 0.889) y por valores actuales de velocidad máxima teórica (V_0) altos ($p < 0.001$, η^2_p =

0.844) comparados con el perfil óptimo estimado. A pesar de que no existen diferencias significativas entre los desequilibrios presentados por ambos grupos en cada momento, resultados complementarios mostraron una tendencia moderada a reducir el desequilibrio de N1 a N2 en el HT y de N1 a N3 en el NT (-11.96% y -7.88%, respectivamente, $p < 0.10$). Se ha registrado un efecto de la altitud sobre las variables del *ippon-seoi-nage* ($p < 0.05$). Así, la aceleración de la fase de extensión de piernas aumentó un 22.95% menos en HT que en NT ($p = 0.03$). Además, el tiempo hasta alcanzar la horizontal del *uke* aumentó en HT y disminuyó en NT (diferencia entre HT y NT = 18.68%, $p = 0.003$). El período de entrenamiento no provocó cambios en las variables de antropometría y de análisis de impedancia bioeléctrica en ambos grupos ($p > 0.05$). No se han observado correlaciones entre las variables mecánicas de la extensión de piernas y la aceleración o velocidad angular transferida al *uke*. Esta asociación no se vio afectada por la exposición aguda o el entrenamiento en altitud.

En concordancia con la literatura, nuestros resultados muestran un incremento en la capacidad de empuje de piernas desde el primer momento de exposición a la altura. Posteriormente, tras un periodo de entrenamiento orientado de potencia muscular, la altitud moderada parece incrementar el pico de rendimiento y acelerar el momento en que este se alcanza. El análisis pormenorizado del efecto de interacción momento × altitud indica que el mayor rendimiento en la velocidad de extensión de piernas y en la altura de salto se obtuvo en HT (alcanzado en N2) con respecto al de NT (alcanzado en N3) ($p < 0.05$). Los parámetros de rendimiento de la técnica analizada no sufrieron cambios en exposición aguda a la altitud moderada y empeoraron tras el periodo de entrenamiento, incrementando los tiempos y reduciendo las aceleraciones producidas en el *uke*. Los cambios en la condición física, junto a los del propio patrón espacio-temporal que puede inducir la exposición a la altitud, ponen de manifiesto la necesidad de ajustar y estabilizar la técnica tanto durante como después de un periodo de entrenamiento en altitud en aquellas disciplinas que incorporen acciones de coordinación compleja. Finalmente, las diferencias entre el coeficiente de variación individual y grupal confirman que cada judoca adapta la ejecución del *ippon-seoi-nage* a sus características, ejecutándolo siempre de la misma manera. No obstante, la ausencia de asociación entre la capacidad de extensión de piernas y la performance del *ippon-seoi-nage* podrían indicar que, por lo menos en la muestra estudiada, la implicación de las piernas durante la ejecución del *ippon-seoi-nage* no fue suficiente de acuerdo con el *gold standard* de la técnica. Estudios futuros son necesarios para profundizar en el análisis de la técnica y en la naturaleza de las adaptaciones de la fuerza y su transferencia al gesto deportivo como consecuencia de la exposición y entrenamiento en hipoxia.

Research projects

During this doctoral thesis I have participated in the following research projects:

1. Effect of a resistance training under different types of hypoxia on the hypertrophy and its link with neuromuscular markers of metabolic stress and associated mechanisms (PGC2018-097388-B-I00; supervised by Belén Feriche; 72600€; 2019-2022) funded by the Spanish Ministry of Science, Innovation and Universities.

2. Effect of hypertrophic training at moderate altitude on the response of markers of metabolic stress and associated muscular growth mechanisms (A-SEJ-246-UGR18; supervised by Paulino Padial; 6400 €; 2020-2021) funded by the Andalusian Regional Government.

3. Building of a normobaric hypoxia laboratory (EQC2019-005832-P, supervised by Belén Feriche; 246,419.91€; 2019-2020) funded by the Spanish Ministry of Science, Innovation and Universities, State Research Agency and European Union.

4. Research network on Hypoxia, Sport and Health (HIPOXSPORT 27/UPB/19; supervised by Ginés Viscor; 8.000€; 2019) funded by the Spanish Sport Council.

5. Influence of the exposure strategy to moderate hypoxia on the adaptations to the muscular power training (DEP2015-64350-P; supervised by Belén Feriche; 71148€; 2016-2019) funded by the Spanish Ministry of Economy and Competitiveness.

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Research stays

Stay 1: A five-week research stay (May-June 2017) was performed at the Valencian Judo High Performance Center and at the University of Valencia (Spain), to monitor the training and testing of the elite judokas during the training camp at sea level and also during the two-week control period.

Stay 2: A three-month research stay (January-April 2020) was carried out at the French Institute of Sport (INSEP, Paris), to study the effect of simulated hypoxia and heat (environmental stress) on the metabolic cost of transportation.

Publications arising from this doctoral thesis

Scientific articles

Almeida, F., Bonitch-Góngora, J., Padial, P., de la Fuente, B., Morales-Artacho, A. J., & Feriche, B. (2018). Effect of acute exposure to moderate altitude on kinematic variables of the ippon-seoi-nage and its relationship with the countermovement jump in elite judokas. *PLoS ONE*, 13(10), e0206297. https://doi.org/10.1371/journal. pone.0206297

Almeida, F., Padial, P., Bonitch-Góngora, J., de la Fuente, B., Schoenfeld, B. J., Morales-Artacho, A. J., Benavente, C. & Feriche, B. (under revision). Effect of altitude training on physical and technical performance in elite judokas.

Conference proceedings

Almeida, F., Bonitch-Góngora, J., Padial, P., de la Fuente, B., Calderón, C., Schoenfeld, B. J., & Feriche, B. (2019). *Effect of ascent and training at moderate altitude on elite judokas performance.* Book of Abstracts, XII International Symposium in Strength Training and IronFEMME Study / I NSCA Spain National Conference, Madrid, 121-122, 978-84-09-16216-1.

Almeida, F., Bonitch-Góngora, J., Padial, P., Morales-Artacho, A. J., Schoenfeld, B. J., de la Fuente, B., Calderón, C., & Feriche, B. (2018). Effect of a power-oriented resistance training program at moderate altitude on the force-velocity relationship in elite judokas. *Journal of Strength and Conditional Research*, 32(9), e15-e16. Best oral presentation in

the Resistance Training and Strength Area of the 6^{th} NSCA International Conference in Madrid.

Almeida, F., Bonitch-Góngora, J., Padial, P., García-Ramos, A., Pérez-Castilla, A., Morales-Artacho, A., de la Fuente, B., Calderón, C., & Feriche, B. (2017). *Análisis de los parámetros mecánicos del ippon-seoi-nage y su relación con el perfil fuerza-velocidad en judokas de élite.* Book of Abstracts, X International Symposium in Strength Training, Madrid, 271, 978-3-9818414-0-4.

Almeida, F. (2017). *Análisis de los parámetros mecánicos del ippon-seoi-nage mediante acelerometría triaxial.* I Seminario Internacional Ciencia y Judo, Elche.

Other contributions

Scientific articles

Ortega-Rodríguez, R., Feriche, B., **Almeida, F.**, Bonitch-Góngora, J. & Padial, P. (2020). Effect of the pronated pull-up grip width on performance and power-force-velocity profile. *Research Quarterly for Exercise and Sport.* https://doi.org/10.1080/02701367.2020.1762835

Feriche, B., Schoenfeld, B. J., Bonitch-Góngora, J., de la Fuente, B., **Almeida, F.**, Argüelles, J., Benavente, C., & Padial, P. (2019). Altitude-induced effects on muscular metabolic stress and hypertrophy-related factors after a resistance training session. *European Journal of Sport Science, 18,* 1-10. https://doi.org/10.1080/17461391.2019.1691270

García-Ramos, A., Pérez-Castilla, A., Morales-Artacho, A.J., **Almeida, F.**, Padial, P., Bonitch-Góngora, J., de la Fuente, B., & Feriche, B. (2019). Force-velocity relationship in the countermovement jump exercise assessed by different measurement methods. *Journal of Human Kinetics*, 67(1), 37-47. https://doi.org/10.2478/hukin-2018-0085

Conference proceedings

Benavente, C., Feriche, B., Schoenfeld, B. J., Bonitch-Góngora, J., de la Fuente, B., **Almeida, F.**, Ortega-Rodríguez, R. & Padial, P. (2020). *Acute moderate altitude effect on metabolic response after a hypertrophy-oriented resistance training session. Journal of Strength and Conditional Research*, 34 (3), e25. 1st Oral Communication Award in the General Area of the XII International Symposium in Strength Training and IronFEMME Study / I NSCA Spain National Conference in Madrid.

Stirn, I., Tomazin, K., Smajla, D., Strojnik, V., Padial, P., **Almeida, F.**, Morales-Artacho, A., Bonitch-Góngora, J., de la Fuente, B., Calderón, C., Pérez-Castilla, A., & Feriche, B. (2018). *Effect of altitude strength training on neuromuscular function*. Book of Abstracts, 23rd Annual Congress of the European College of Sport Science, Dublin, 263, 978-3-9818414-1-1.

Book chapters

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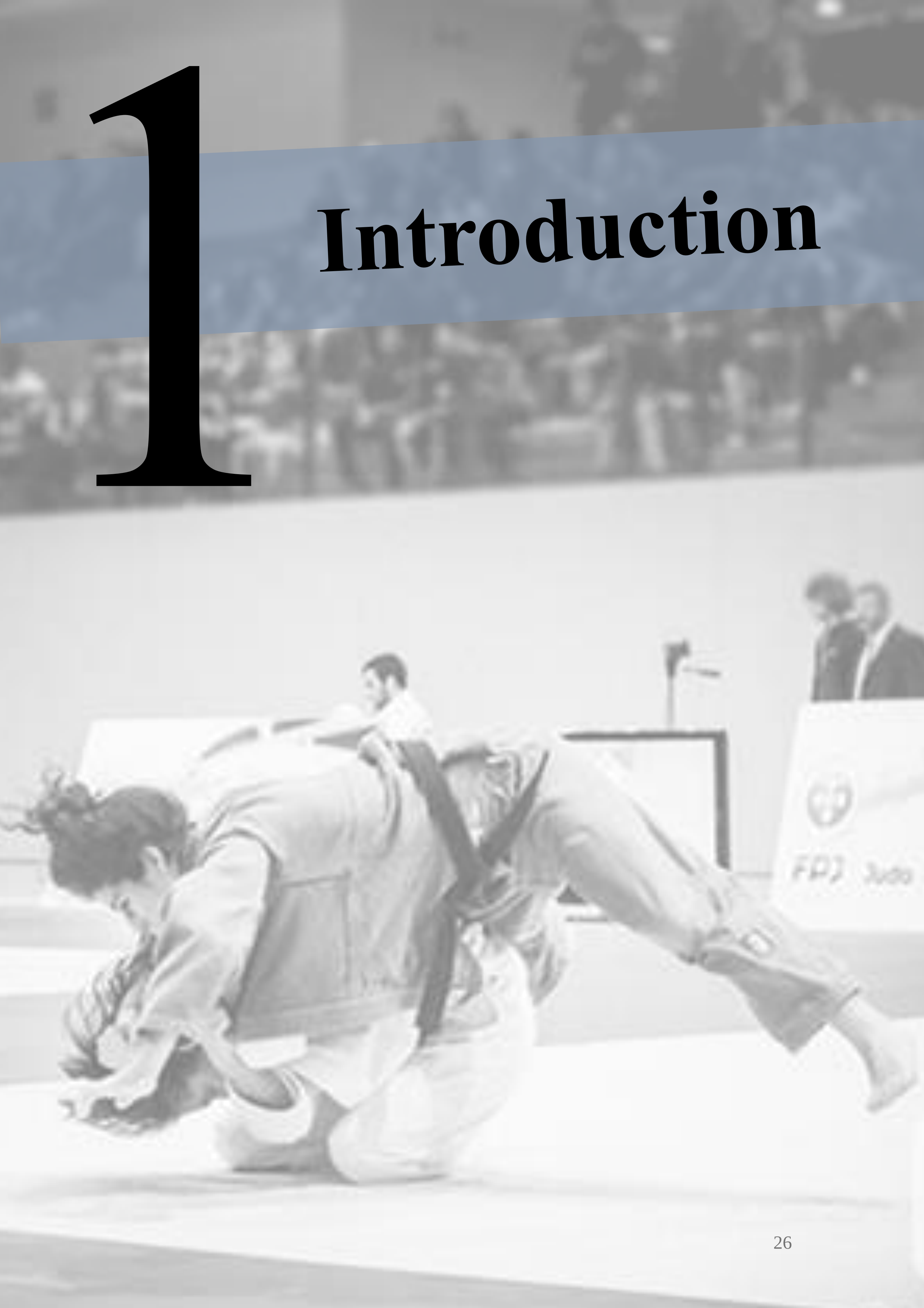
Bonitch-Góngora, J. & **Almeida, F.** (2018). Entrenamiento de la resistencia en judo. En: R. Hernández (Ed.), *Judo: Nuevas Perspectivas sobre Metodología y Entrenamiento* (pp. 151 – 171). Wanceulen Editorial Deportiva S. A.



1 Introduction

1.1. Judo

1.1.1. Characteristics of judo competition

Judo is a high-intensity intermittent sport that requires complex skills and tactical excellence for success (Degoutte et al., 2003). Typically, judo medalists perform five to seven 4-minute combats during international competitions. Athletes fight on a square surface of 10 x 10 m, surrounded by a security zone of at least 2 m (Fig 1).

Figure 1. Official combat areas.

The combat begins with both judokas trying to gain an advantage by gripping the opponent *judogi* (judo suit) (Calmet et al., 2010). After getting a proper grip the judoka tries to apply a throwing technique (Courel et al., 2014; Kajmovic & Izet, 2014). Consequently, the competitor could end the bout by scoring *ippon* (full point), or score *wazari* (half point), or not score at all. The fight can continue on the ground if an *ippon* was not scored previously (Boguszewski, 2011). On the ground, judokas can score *ippon* with a hold-down, joint lock or strangulation technique (Miarka et al., 2014). When the time allotted for the combat finishes and the scores are equal for both athletes, the result of the contest is decided by a golden score, i.e., the combat is extended until one of the judokas scores the first point (Franchini, Sterkowicz, et al., 2011). Thus, a judo match may last from a few seconds to several minutes, depending on the scores obtained by the competitors. However, a typical high-level judo match lasts ~ 3 minutes, with periods of 20-30 seconds of activity and 5-10 seconds of pause (Castarlenas, 1997; Marcon et al., 2010; Miarka et al., 2016).

As judo athletes have to perform a great number of actions during each match, the physical demand of a single match is high. To be effective, judo techniques should be applied with accuracy, within a good window of opportunity, with strength, velocity and power (Fig 2). According to Franchini et al. (2011), high muscular strength and endurance are required, mainly during the struggle to gain a dominant grip and unbalance the opponent, as well as high muscle power to perform throwing techniques involving both lower- and upper-body muscle groups. The high-intensity efforts are continuously repeated during the matches under increasingly unfavorable metabolic conditions (Bonitch-Domínguez et al., 2010; Iglesias et al., 2003). These successive efforts may induce force decrement due to fatigue and consequently determine the performance over the tournament, especially in the forearm and shoulder muscles (Bonitch-Góngora et al., 2012; Detanico et al., 2015; Kons et al., 2018). Although the key actions in judo are essentially reliant on anaerobic metabolism, aerobic fitness seems to be very important since it allows better recovery during the short rest periods between high-intensity efforts and between matches (Franchini, Del Vecchio, et al., 2011). Indeed, Julio et al. (2017) analyzed the energy system contribution in judo combats of different duration (from 1 to 5 minutes) and found a predominance of the oxidative system from the first minute of combat up to the end (70%) compared with the anaerobic systems (8% for the glycolytic and 21% for the alactic systems). Thus, judokas need to develop both anaerobic and aerobic power and capacity.

Figure 2. Judo throw (uchi-mata) applied during an official combat.

All these findings indicate that judo is a complex sport that comprises a number of specific characteristics to achieve a high level in competition. Furthermore, judo is a weight-classified sport, in which both female and male athletes are divided into seven weight categories (International-Judo-Federation, 2020). However, there is little research on how the relationship between physical and technical-tactical performance differs according to weight category. In this regard, it is known that body structure can play a determinant role in the type of techniques applied (Franchini, Takito, & Bertuzzi, 2005) and in the achievement of top judo performance (Claessens et al., 1987; Franchini et al., 2014; Sterkowicz-Przybycień & Franchini, 2013). Thus, the typical somatotype of male judokas from the weight categories of -60 and -66 kg is balanced-mesomorph, while from categories of -73 to +100 kg is endomorphic-mesomorph (Franchini et al., 2014; Sterkowicz-Przybycién, 2012). Morphologically, male judo athletes could be grouped in four divisions: -60 and -66 kg, -73 and -81 kg, -90 and -100 kg, and +100 kg (Franchini et al., 2014). In addition, elite judokas have significantly larger fat-free mass (Callister et al., 1991; Kubo et al., 2006), higher circumference (flexed arm, forearm, and medial calf) and breadth values (humerus and femur epicondyles) than non-elite judokas (Franchini, Takito, Kiss, et al., 2005). However, when the athletes competitive level is more similar (national team members and their reserves) no anthropometrical differences have been found (Franchini et al., 2007).

On the other hand, problems associated with the weight management in judokas have been well studied. Rapid weight loss (RWL) is a common strategy used by judo athletes to compete in weight categories that are usually incompatible with their body types (Artioli et al., 2016). By quickly reducing weight, athletes try to obtain physical and mental advantages (Gann et al., 2015). Immediately after weigh-in judokas usually regain weight (Franchini et al., 2012), building a pattern of weight loss and regain called weight cycle. Thus, judokas typically reduce ~ 2 to 10% of their body weight, mostly in the 2-3 days prior to weigh-in. To achieve this, various methods that lead to intentional hypohydration and/or starvation are used (Berkovich et al., 2016; Pettersson & Berg, 2014). Namely, long periods of fasting (>24 h), exercising in plastic suits, saunas, hot baths and severe restriction of fluid intake (Artioli, Gualano, et al., 2010).

The effects of intentional RWL on health and performance have long been a matter of concern (Doshner, 1944; Tuttle, 1943). Short-term health risks related to RWL include 1) hypohydration and reduced plasma volume (Reljic et al., 2013), impairing cardiovascular efficiency (Gonzalez-Alonso et al., 1997), 2) difficulty to control body temperature (Sawka et al., 1998) and 3) acute hormonal imbalance (Degoutte et al., 2006; McMurray et al., 1991). The long-term consequences of RWL comprise 1) bone loss (Prouteau et al., 2006), 2) immune suppression (Suzuki et al., 2003), 3) hormonal imbalance (Roemmich & Sinning, 1997a), 4) incomplete attainment of full growth potential (Roemmich & Sinning, 1997a, 1997b), and 5) increased risk of becoming overweight or obese after retirement from the sport (Saarni et al., 2006). Regarding performance, RWL did not affect strength and muscle power regardless of the duration of the recovery period following weight loss (Koral & Dosseville, 2009; Marttinen et al., 2011; Serfass et al., 1984). Conversely, the effects of RWL on aerobic and anaerobic performance are highly dependent on the recovery period available after the weigh-in. Thus, there were negative effects on performance after very brief or nonexistent recovery periods (<1 h) (Filaire et al., 2001; Hall & Lane, 2001; Hickner et al., 1991; McMurray et al., 1991; Smith et al., 2000; Webster et al., 1990), whereas no impairments in physical performance were registered after longer recovery periods (>3 h) (Artioli, Iglesias, et al., 2010; Mendes et al., 2013). All these findings seem to indicate that general competitive performance is not affected by weight loss whenever it is followed by a sufficient recovery period (Artioli et al., 2016).

From a practical perspective, a comprehensive understanding of elite judokas characteristics can provide insightful information regarding what is needed for competitive success, which is extremely valuable for coaches and athletes (Franchini, Del Vecchio, et al., 2011).

1.1.2. Leg muscular power requirements in judo

Generally, the conditional and technical-tactical profiles of judo winners significatively differ from those of judokas that do not reach the medals (García-García et al., 2007). Focusing on strength requirements, some questions may arise: Which strength manifestations differentiate a judo champion from one who is not? If there are any differences, do they transfer to specific technical gestures? The answer to those questions would provide key information to design suitable training programs.

Few studies provide leg power-related values in judokas and/or compare judokas from different competitive levels. Monteiro (2013) in his doctoral thesis compared jump performance of elite and non-elite Portuguese judokas. Elite judokas reported higher values of rate of force development in squat jump (SJ) and of strength production until the peak velocity (PV) was achieved in countermovement jump (CMJ). Other studies also observed enhanced jumping performance in elite judokas compared to non-elite (Detanico et al., 2016; Zaggelidis & Lazaridis, 2013) and to recreational judokas (Fagerlund & Hakkinen, 1991). In addition, senior judo athletes displayed higher performance in the vertical jump when compared with juniors (Tumilty et al., 1986).

Considering the adverse metabolic conditions induced by the combats (Mickiewitz et al., 1991; Serrano et al., 2001), it would be important to know if it affects the leg muscle power capacity. Up until now, there are few studies on leg power performance after real or simulated competitions. Julio et al. (2018) found increased lower-limb muscle power after five combats with different duration (1 to 5 minutes), performed in different days in a randomized order. Bonitch-Domínguez et al. (2010) reported a small, but non-significant, muscle power increase in the concentric ½ squat after four 5-minute combats, with 15 minutes of passive rest between them. Likewise, Detanico et al. (2015) did not find changes in the CMJ power after three combats, although a decrease in the jump height was reported. Other studies did not find changes in the CMJ height after one (Carballeira & Iglesias, 2007) or two combats (Iglesias et al., 2003). These findings joined to the time-motion analysis seem to suggest that the leg explosive actions occur sporadically to perform the attacks, likely with sufficient time between the attacks to recover energy supplies and dissipate fatigue. Therefore, training programs should focus on the improvement of the leg power capacity.

1.1.3. Technique in judo

Performance analysis is widely considered beneficial for the training process, because it provides an accurate description of sports behaviors in their training/competition contexts (McGarry, 2013). Particularly in judo, research has seen a growth in the analysis of technical and tactical dynamics (Calmet et al., 2010), as well as in time-motion analysis, with specific observations of effort-pause ratio and duration of the combat phases (Marcon et al., 2010; Miarka et al., 2014).

The shortness of actions, the possibility of simultaneous actions and multiple interactions during a judo combat lead to a long and difficult analysis. Despite its difficulty, analyzing and understanding the dynamics of a judo match is essential to help coaches guide their athletes through this complexity. The main goal of a judoka is to throw his opponent to the ground or to obtain control during ground fight. The effectiveness of these attacks depends on the technical and tactical capacity to adapt to changing situations (Franchini et al., 2008). In this sense, a judo combat may be conceived as a set of action sequences between both judokas (Calmet et al., 2010). These sequences form an unique complex system that vary from one combat to the other but that may be studied with similar methods (Zwirn, 2003). The uncertainty of the opponent's behavior and the need to be constantly adapting to it, is a skill that both coaches and competitors must develop (Calmet et al., 2010). The classical observational analysis (based on the attack and gripping directions) highlights the fact that judokas attack in four or six different directions with a single grip (Calmet, 2006; Franchini et al., 2008). In addition, every grip, displacement and attack in several complementary directions represent the judoka's attacking system (Calmet, 2006; Franchini et al., 2008).

Regarding time-motion analysis, research allowed to systematize different phases in a judo match: 1) break phase: period between the combat interruption signal (*mate*) and the signal for match restart (*hajime*) (~ 10 s); 2) preparation phase: period between the first step taken after the referee's signal to start (*hajime*) and the first grip (*kumi-kata*) (~ 5 s); 3) grip phase (*kumi-kata*): period between the start and release of the grip (~15 s); 4) technique/attack phase: time spent on each attack throughout the match (~ 1 s) and 5) groundwork phase (*ne-waza*): time spent on each ground fight (~ 17 s) (Miarka et al., 2014; Miarka et al., 2011). This systematization may help coaches to design training strategies more suited to improve performance during the combat.

While a time-motion and technical-tactical analysis help to understand the combat complex dynamics, a descriptive kinematic analysis of judo throws can explain the motor skills used by athletes. Technical efficacy in judo is determined by the technical and tactical aspects discussed above (*kumi-kata*, directions of attack, moment of the attack, etc.), but also by the judoka technical skills. These skills were originally classified by Jigoro Kano under four groups of throwing techniques: *te-waza* (hand techniques), *koshi-waza* (hip techniques), *ashi-waza* (leg/foot techniques) and *sutemi-waza* (techniques that sacrifice personal balance to throw). Each technique comprises three phases: *kuzushi* (unbalance), *tsukuri* (entry and proper fitting of the body into the position taken just before throwing) and *kake* (throwing action) (Fig 3).

Figure 3. Technique phases: kuzushi, tsukuri and kake.

Throwing techniques are known to require high levels of strength and muscle power to be performed at high velocities and against a great resistance from the opponent (Bonitch-Domínguez et al., 2010; Franchini, Del Vecchio, et al., 2011). Strength in judo has been studied through the assessment of basic strength exercises (bench-press, back squat and squat jump exercises) (Aruga et al., 2003; Bonitch-Domínguez et al., 2010), but its transference to technical performance has not been studied. Two studies used specific exercises to assess strength in judo, finding that elite vs. non-elite judokas display higher peaks of ground reaction force and less time to reach these peaks in *uchi-mata*, *harai-goshi* and *hane-goshi* (Zaggelidis & Lazaridis, 2013) and higher power on a specific sleeve pulling action (*hikite*) using a pulley machine (Iteya et al., 2005).

Judo techniques have been traditionally analyzed through systematic observation to improve the technical learning process (García-García et al., 2007; Gomes et al., 2017). In this line, the technical performance of highly-experienced judokas was reported to be less affected by fatigue compared to less experienced ones (García-García et al., 2007), which means they have the technique better assimilated and are able to maintain their skill under stressful situations. During technical sessions, performing a pre-*kuzushi* (i.e., unbalance action) previous to each technique may help learners to manage pulling and pushing actions in order to unbalance the opponent (Gomes et al., 2017). An inadequate knee, hip and trunk positioning during technical performance results in problems related to the throwing direction of the *seoi-nage* (Gutiérrez-Santiago et al., 2013).

Some authors have analyzed judo techniques from a biomechanical perspective using tridimensional analysis via camera systems (Blais et al., 2007; Imamura et al., 2006; Ishii, Ae, Suzuki, et al., 2018). Thus, Ishii et al. (2018; 2014; 2016; 2013) compared the performance of *seoi-nage* between elite and university Japanese judokas. Elite judokas achieved higher velocity in the sleeve pulling action (*hikite*) (Ishii & Michiyoshi, 2014), in the displacement of their center of mass (COM) (Ishii, Ae, Suzuki, et al., 2018; Ishii et al., 2016) and in the hip action (Ishii, Ae, Koshida, et al., 2018; Ishii & Michiyoshi, 2014) while throwing. In addition, elite judokas generated higher upper-limb angular velocity, starting the turning phase of the *seoi-nage* with a rotation of the lower-body followed by the upper-body. It seems that the minimization of the upper-body rotation in the early turning phase allows elite judokas to cover their *seoi-nage* by not given clear visual and somatosensory inputs to their opponents (Ishii et al., 2013). Blais et al. (2004) underlined the complexity of judo techniques which require simultaneous management of different actions in three different planes. To illustrate this, *seoi-nage* key points were described through the analysis of kinematic parameters of five elite French judokas. Specifically, the hip-shoulder rotation, the pre-pivot inclination, the post-pivot inclination, the vertical offset and the anteroposterior offset. Furthermore, the main driving moments during *seoi-nage* are generated by the lower-limbs and the trunk and not by the upper-limbs, and the higher energy expenditure occurs during the *tsukuri* phase (Blais et al., 2007).

However, these results should be interpreted with caution, due to the reduced size of the sample in most of the studies (n<10), although it was of high quality. It is also worth noting that the camera systems used were highly expensive, not portable and recorded at a 250 Hz sampling rate, which is insufficient to analyze a technique performance of ~1.2 s. Moreover, considering that judokas should move high loads (the opponent's body mass), it is important to focus on the *uke*'s mechanical parameters, in addition to those related to the *tori*. Indeed, the velocity and acceleration that *tori* is able to transmit to unbalance *uke* and throw is a fundamental parameter (Imamura et al., 2006), and not only *tori*'s capacity to move his own body at high speed before colliding with *uke*. To date, only two studies analyzed the *seoi-nage* kinematic parameters from this perspective. Ishii et al. (2014) found that elite vs. university judokas induced a greater angular velocity on the *uke*'s COM at the instant that he was completely lifted up. Imamura et al. (2006) reported that *seoi-nage* created the smallest impulse and force onto *uke* when compared to *osoto-gari* and *harai-goshi*. Nevertheless, *seoi-nage* maintained a large forward momentum on *uke*'s body even after losing the body contact with *tori*. This indicates that a shorter stature, speed, and skill to fit-in properly under the *uke* and roll him over the shoulder without compromising forward momentum is crucial (Imamura et al., 2006).

It is important to highlight that the majority of the studies selected the *seoi-nage* as the technique to analyze (Blais et al., 2007; Imamura et al., 2006; Ishii, Ae, Suzuki, et al., 2018), probably because it is one of the most used techniques in judo (Ishii, Ae, Suzuki, et al., 2018). To perform *seoi-nage*, *tori* has to pull *uke*'s *judogi* (judo suit) to take him off-balance, turning to position himself underneath the *uke* before finally throwing him over his shoulder. The leg extension action has been considered a fundamental parameter in the technical performance of *ippon-seoi-nage* (Blais & Trilles, 2004; Ishii & Ae, 2015; Ishii, Ae, Koshida, et al., 2018), responsible for the last part of the technique (*kake*).

All these findings warrant the need to study the kinematic parameters of the judo technique to ultimately provide a better understanding of the factors that constitute a mechanically efficient throw. Additionally, knowing the parameters that impact the technical learning and efficacy would be fundamental to reduce the time needed for the learning process and technical mastery.

1.2. Power-oriented resistance training

1.2.1. Factors that affect muscle power capacity

Given the plasticity of the skeletal muscle, resistance exercise variables can be manipulated to provide a specific training stimulus. These variables generally include the muscle action, load, volume, type and order of the exercises, inter-set rest periods, repetition velocity and training frequency (Bird et al., 2005). Resistance exercise induce a complex cascade of biological responses, including metabolic and hormonal changes, intramuscular signaling processes and protein synthesis (Spiering et al., 2008).

Maximal muscular power is determined by the parameters of the force-velocity (F-V) relationship, being maximized at a combination of submaximal force and velocity values (Cormie et al., 2011a) (Fig 4). Likewise, the length-tension relationship plays an important role in maximal power capacity, because the force production is maximized when the sarcomere length provides an optimal over-lap between the actin and myosin filaments (Lieber et al., 1994). Maximal power production is also influenced by the type of muscle action involved, which can include eccentric or concentric contractions, as well as actions involving any combination of eccentric, isometric and concentric contractions (Komi, 1986).

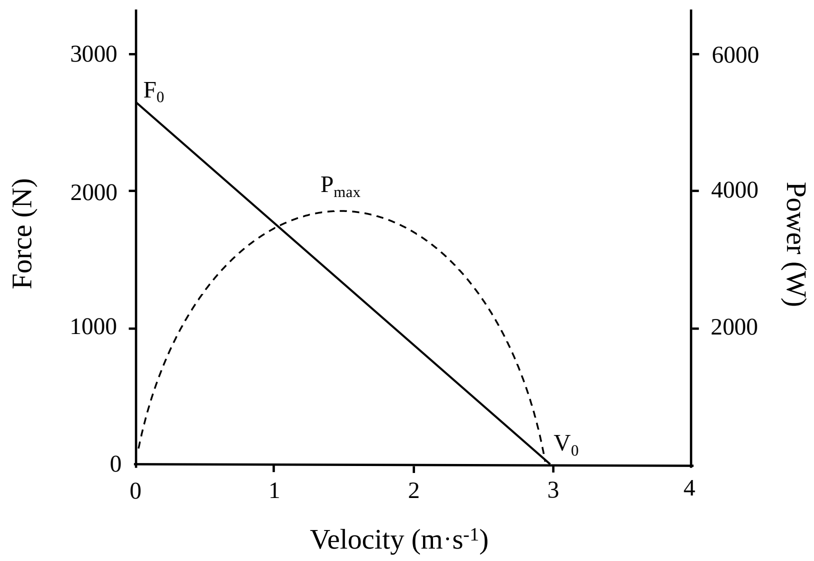


Figure 4. Typical force-velocity relationship from a vertical jump, showing the maximal theoretical force (F_0), velocity (V_0) and power (P_{max}) of the lower-limbs. Adapted from Morin & Samozino (2018).

Muscle power capacity is determined by the contractile capacity of the muscles involved. This contractile capacity is influenced by a series of morphological factors such as the fiber type, muscle architecture and tendon properties (Cormie et al., 2011a). The enhancement of type II fibers should be prioritized in power sports due to their greater capacity to generate power per unit cross-sectional area (Malisoux et al., 2006; Widrick et al., 2002). Although ~45% of the variance in muscle fiber type is believed to be genetically determined (Simoneau & Bouchard, 1995), muscle fiber plasticity in response to training stimulus is well described in the literature (Lieber, 2010; Widrick et al., 2002). In addition to morphological factors, neural factors responsible for muscle activation such as motor unit recruitment (Enoka & Fuglevand, 2001), firing frequency (Patten et al., 2001) and synchronization (Semmler, 2002), as well as inter-muscular coordination (Sale, 2003) strongly affect muscle power production (Cormie et al., 2011a) (Fig 5).

1.2.2. Training considerations

Sport actions in general (Baker, 2001; Kraemer & Newton, 2000; Sleivert & Taingahue, 2004) and judo throws in particular are known to require high levels of muscular power (Bonitch-Domínguez et al., 2010; Franchini, Del Vecchio, et al., 2011), mainly due to small time windows to apply the necessary force for a suitable technical performance. Therefore, the design of training programs to enhance power capacity of athletes is crucial to improve sports performance (Haff & Nimphius, 2012).

According to Cormie et al. (2011b) extensive review on how to develop maximal neuromuscular power, there is a fundamental relationship between strength and power, which makes improving and maintaining maximal strength essential for the long-term development of power. Therefore, an athlete cannot achieve high power levels without first being relatively strong (Miyaguchi & Demura, 2008; Stone et al., 2003). In this sense, heavy strength training programs involving untrained to moderately trained subjects not only improve maximal strength but also enhance maximal power output (Cormie et al., 2010; McBride et al., 2002). As maximal strength improves, the window of adaptation for further strength enhancement becomes smaller. Therefore, increases in maximal power output following strength training are also expected to become smaller and more velocity-specific (Newton & Kraemer, 1994). Further muscular power improvement in well-trained athletes requires a multifaceted approach combining different training strategies targeting specific areas of the F-V relationship (Kraemer & Newton, 2000; Newton & Kraemer, 1994).

Movement pattern, load and velocity specificity must be considered when designing power training programs that should include ballistic, plyometric and weightlifting exercises and be as varied as possible (Cormie et al., 2011b). The use of traditional resistance training (RT) exercises such as squat or bench-press allows athletes to move very high loads, inducing improvements in muscle cross-sectional area and neural drive (Campos et al., 2002). However, significant increases in maximal power following training with traditional exercises occur mainly in subjects with low to moderate strength levels and decrease as strength levels increase (Newton & Kraemer, 1994; Wilson et al., 1997). Consequently, further improvement in maximal power requires the involvement of more mechanically specific movements (Cormie et al., 2011b). Thus, ballistic exercises such as SJ or bench-press throw avoid any deceleration phase, requiring athletes to accelerate throughout the entire range of motion to the point of projection (i.e. take-off or release) (Cormie et al., 2007). This type of movement induces higher concentric velocity, force, power and muscle activation than a similar traditional resistance training exercise (Cormie et al., 2007), although it can only use lower loads due to its characteristics. Plyometric exercises are characterized by rapid stretch-shortening cycle muscle actions (Davies et al., 2015) with an intrinsic ballistic nature. This kind of exercises significantly improve maximal power output during sport-specific movements (Chimera et al., 2004), although only on low-load / high-velocity stretch-shortening cycle movements (Tricoli et al., 2005). Lastly, weightlifting exercises such as snatch or clean and jerk are usually included in power training programs from different sports (Cormie et al., 2011b). The intrinsic high-force / high-velocity nature of weightlifting exercises allows to generate high power outputs with a wide range of loading conditions (Kawamori et al., 2005). Therefore, the nature of these exercises and their similarity to the movement patterns of several sports suggest that weightlifting exercises are effective in power training (Ayers et al., 2016; Hori et al., 2005). Accordingly, Suchomel et al. (2018) stated that weaker/less-skilled athletes should focus first on developing their strength before using power-type exercises and training methods (plyometrics and potentiation complexes). In contrast, stronger/more-skilled athletes may emphasize power-type exercises and training strategies while maintaining/improving their strength levels (Suchomel et al., 2018).

It is known that muscle power production is highly dependent on the exercise loading conditions (Cormie et al., 2007; Kawamori & Haff, 2004). Heavy loads (>80% 1RM) are often prescribed in conjunction with traditional RT exercises mainly to improve maximal strength and consequently power (Harris et al., 2000; McBride et al., 2002). Whereas light loading conditions (<60% 1RM) in conjunction with ballistic and/or plyometric exercises are generally used to train the power capacity at velocities similar to those encountered in the sports movements (Chimera et al., 2004; McBride et al., 2002). The optimal load or the load that elicits maximal power production in a specific movement is considered a potent stimulus for improving maximal power (Kawamori & Haff, 2004). This optimal load is highly dependent on the nature of the movement involved, varying significantly across different exercises (Cormie et al., 2011b). Specifically, the optimal load is reported to be 30-40% of squat 1RM in CMJ (Baker et al., 2001), 56% 1RM in squat (Cormie et al., 2007) and up to 70–80% 1RM in snatch and clean (Cormie et al., 2007; Kawamori et al., 2005). Considering that light loads enhance the high-velocity area of the F-V relationship, while heavy loads target the high-force area, it is recommended to combine both loading conditions to produce the desired strength adaptations while underpinning rate of force development and power characteristics that are important to sport performance (Suchomel et al., 2018).

Regardless of the type of contraction, load or movement velocity of the exercises used, maximal intention to move fast is vital to elicit muscle power adaptations (Cormie et al., 2011b). Furthermore, considering that limited neuromuscular fatigue during explosive training is a key factor to maintain its high intensity and therefore maximize adaptation (Haff & Nimphius, 2012; Pareja-Blanco et al., 2014), few repetitions per set

(3-6 rep/set), few sets (3-6 sets), as well as complete resting periods between sets (3-5 minutes) are common power training guidelines (Haff & Nimphius, 2012). Contrast methodologies, alternating heavy- (80-95% 1RM) with light-load (30-60% 1RM) exercises to generate a stimulus of postactivation potentiation on the neuromuscular system are also frequently used to enhance muscle power capacity (Alves et al., 2010; Cometti, 1998; Sale, 2002). In addition to the loads used in contrast training, different regimens of contraction (e.g.: concentric + plyometric exercises) and exercises (e.g.: general + sport-specific exercises) can be used (Cometti, 1998). Further research found that including short rest intervals (15-30 seconds) between a group of repetitions within a set (i.e., cluster training) seems to lead to greater power training adaptations compared with traditional set configurations (Hansen et al., 2011; Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, & Feriche, 2018). A new approach based on velocity monitoring during RT (i.e., velocity-based training) is being used to improve muscle power gains (Gonzalez-Badillo et al., 2017; Pareja-Blanco et al., 2014). The use of movement velocity to prescribe training load is supported by the strong and stable relationship observed between movement velocity and % 1RM, when maximal velocity is applied (Conceição et al., 2016; Gonzalez-Badillo & Sanchez-Medina, 2010; Sanchez-Moreno et al., 2017). This approach allows to focus on the velocity generated during RT which is of paramount importance to the transference of the gains to sport-specific movements. In addition, it seems to be an effective method to assess fatigue development during training (Sanchez-Moreno et al., 2017), which is vital to improve power training methods (Fig 5).

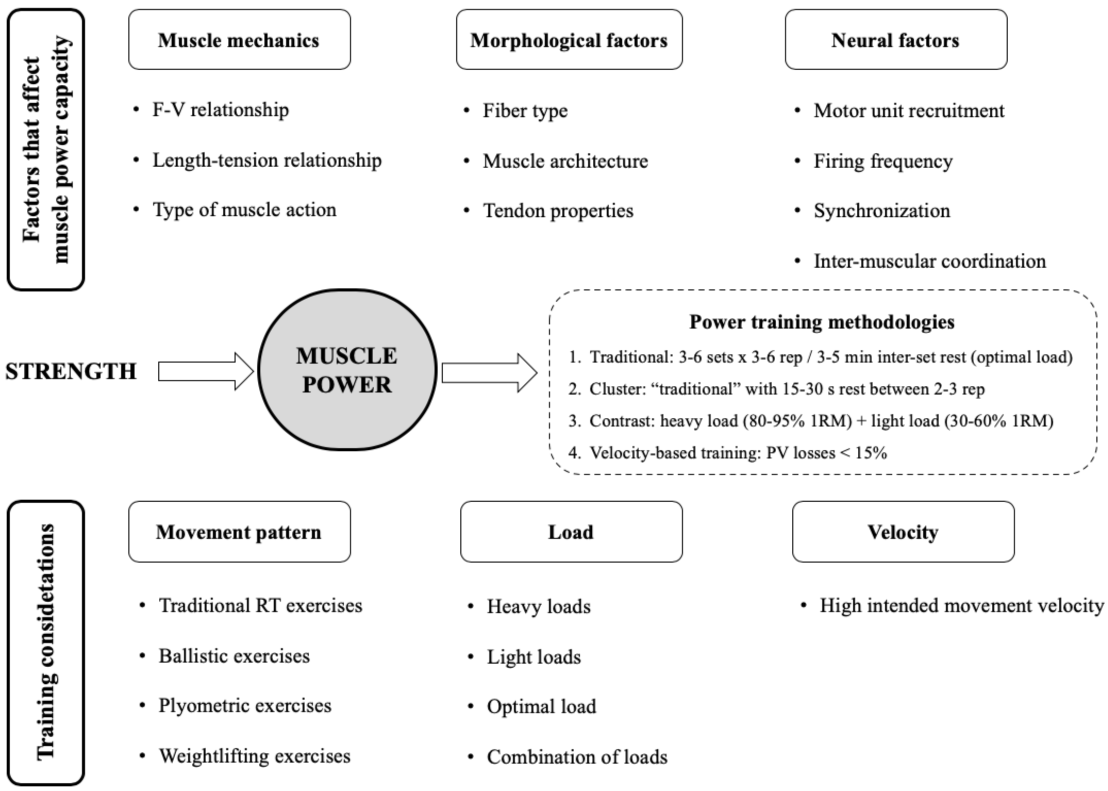


Figure 5. Factors that affect muscle power capacity, training considerations and common power training methodologies.

1.3. Leg strength performance assessment

A holistic approach comprising physiological, biomechanical, anthropometric and performance measures should be taken when assessing the athletic profile of an individual (McMaster et al., 2014). These assessments should be sport-specific (McMaster et al., 2014) and individualized for each athlete (Jiménez-Reyes, Samozino, Brughelli, et al., 2017).

Muscle strength assessment is of paramount importance in sport (McMaster et al., 2014), mainly for prescribing individualized RT programs (Scott et al., 2016) and for assessing the training adaptations (Morin & Samozino, 2016). Strength assessment include both isometric and dynamic strategies. Isometric strength tests are less used because they require expensive measurement systems (McMaster et al., 2014), such as force plates or strain gauges, and higher expertise to use them, whereas dynamic tests are easier to access and use. Moreover, isometric actions are less common in sport and have a limited transference to dynamic actions, which reduces the general interest in this kind of strength assessment. On the other hand, 1RM testing, a versatile procedure to estimate maximal dynamic strength, is the most commonly assessed (McMaster et al., 2014). 1RM can be determined through direct methods, mainly by a maximal incremental loading test, or through indirect methods, such as repetitions to failure tests or movement velocity monitoring. Several factors including testing equipment, measurement system, movement pattern, contraction type, range of motion (eccentric depth), warm-up strategy, motivation and loading scheme should be controlled to guarantee 1RM validity and reliability (McMaster et al., 2014).

Although maximal strength is very important for sport performance (Suchomel et al., 2016), the ability to apply force at high velocities is considered fundamental in many sport-specific situations where force must be applied in very brief periods of time (Kraemer & Newton, 2000). Therefore, there is an increasing interest on explosive performance assessment. For this purpose, jumping performance during controlled experimental conditions has been widely tested, due to its similarity with sports tasks (Samozino et al., 2014). Particularly, CMJ, due to its stretch-shortening cycle action, is the most commonly used exercise in sports training and testing (Morin & Samozino, 2018).

Different measurement devices (force platforms, linear velocity transducers, accelerometers, smartphone applications, infrared platforms, jump mats, etc.) have been used to test the vertical jump with valid and reliable protocols (Giroux et al., 2015). Measurements of ground reaction force using a force plate, or barbell velocity from a linear velocity transducer have been the two procedures most used to assess the values of force, velocity and power during vertical jumps (García-Ramos et al., 2019). Namely, several studies analyzed the jumping performance assessing variables related to the barbell velocity, as the PV, mean velocity (MV) or mean propulsive velocity (MPV) (McMaster et al., 2014). The PV has been considered the most reliable of the three variables (Perez-Castilla et al., 2019).

The fact that this kind of testing has long been associated with expensive and laboratory-based technologies is the reason for the increasing interest on Samozino's method, since it is a simple method to determine the mean values of force, velocity and power during vertical jumps (Samozino et al., 2008). To use Samozino's equations, vertical jump height, push-off distance and system mass (body mass + external load) must be measured. The push-off distance is the difference between the extended lower limb length (distance from the great trochanter to toes with maximal plantar flexion) and the vertical distance from the great trochanter to the ground with knees flexed at 90º (Samozino et al., 2008). This value is a constant throughout an incremental loading test. Vertical jump height can be accurately determined from the flight time recorded by affordable devices such as infrared platforms or smartphone applications (Balsalobre-Fernandez et al., 2015; García-Ramos et al., 2019). Thus, the mean values of force, velocity and power for each vertical jump are calculated using the following equations (Samozino et al., 2008):

$$\bar{F} = mg\left(\frac{h}{h_{PO}} + 1\right),$$

$$\bar{v} = \sqrt{\frac{gh}{2}},$$

$$\bar{P} = mg\left(\frac{h}{h_{PO}} + 1\right)\sqrt{\frac{gh}{2}},$$

where m is the system mass (kg), g is the gravitational acceleration (9.81 $m \cdot s^{-2}$), h is the jump height (m) and h_{PO} is the push-off distance (m).

The neuromuscular system ability to produce maximal force (F_0, force-axis intercept), velocity (V_0, velocity-axis intercept) and power ($P_{max} = F_0 \cdot V_0/4$) may be estimated by linearly modelling the relationship between the force and velocity mean values obtained during an incremental loading test (i.e., the F-V relationship) (Samozino et al., 2012) (Fig 4). The slope of this linear F-V relationship ($S_{fv} = - F_0/V_0$) represents the F-V mechanical profile of the lower limbs (Samozino et al., 2012). Jumping performance is determined by both P_{max} and S_{fv}. Indeed, two athletes with the same P_{max} may achieve different performances during a vertical jump, due to their respective F-V profiles (Samozino et al., 2012). Therefore, the F-V profile of lower limbs, independently from power capabilities, may be optimized to maximize performance by achieving an optimal balance between F_0 and V_0 (i.e., optimal F-V profile, OP-S_{fv}) (Samozino et al., 2012). The relative difference between current and optimal F-V profiles for a given athlete represents the magnitude and the direction of the imbalance between force and velocity capacities (FV_{imb} in %), which allows to determine the individual force or velocity deficit. If this imbalance favors velocity (force deficit), a heavy-load resistance training to increase force capabilities should be prioritized (Samozino et al., 2014). Conversely, if the imbalance is oriented towards force (velocity deficit), training to enhance velocity capabilities should be applied (Samozino et al., 2014). F-V imbalance thresholds have been defined to categorize the magnitude and the direction of the imbalance presented by an athlete (Table 1). Both the optimal F-V profile and the F-V imbalance can be computed using previously proposed equations based on a biomechanical model (Samozino et al., 2014; Samozino et al., 2012).

Table 1. Force-velocity imbalance thresholds. Adapted from Jiménez-Reyes, Samozino, Brughelli et al. (2017).

Force-velocity imbalance	Thresholds (%)
High force deficit	<60
Low force deficit	60-90
Well-balanced	90-110
Low velocity deficit	110-140
High velocity deficit	>140

1.4. Hypoxia

1.4.1. Definition and types

Hypoxia is defined as a reduction below 150 mmHg in the inspired partial pressure of oxygen (PIO_2), that can be achieved through different combinations of reduced barometric pressure (PB) and/or reduced inspired fraction of oxygen (FIO_2) (Conkin & Wessel, 2008). The hypoxia exposure typically used for research purposes can be differentiated in hypobaric hypoxia (FIO_2 = 0.209; PB < 760 mmHg) or normobaric hypoxia (FIO_2 < 0.209; PB = 760 mmHg) (Millet et al., 2012). Hypobaric hypoxia is generally considered from terrestrial altitudes higher than 1000 m, although it can also be artificially simulated (Garner et al., 1990). Whereas normobaric hypoxia is always obtained by simulated procedures that reduce the FIO_2 (nitrogen dilution or oxygen filtration) (Millet et al., 2010). Traditionally, both types of hypoxia were considered to induce the same physiological response, because the decrease in PIO_2 was thought to be the only factor responsible for it (Millet et al., 2012). However, differences in physiological parameters, such as fluid dynamics, affecting vasoconstriction and other cardiovascular responses regulated by the central nervous system (Conkin & Wessel, 2008; Loeppky et al., 2005) were reported. It has also been observed a greater oxidative stress (Faiss et al., 2013), hyperventilation and lower arterial oxygen saturation levels (SpO_2) (Millet et al., 2012; Saugy et al., 2014). This evidence supports the idea that exposure to real altitude induces a more severe response than normobaric hypoxia, suggesting that altitude training adaptations are more effective than the ones induced by normobaric hypoxia (Saugy et al., 2014). There are also physical changes associated with terrestrial altitudes, such as a reduction in the aerodynamic resistance (Hahn & Gore, 2001; Hamlin et al., 2015; Levine et al., 2008), floatability, gravity (Feriche et al., 2016), environmental temperature and humidity and a rise in the solar radiation (Feriche et al., 2017).

1.4.2. Level of hypoxia

Although the classification varies according to different authors (Bartsch & Saltin, 2008; Imray et al., 2011; Koehle et al., 2014), hypoxia is commonly classified in four levels: low (<1500 m; $FiO_2 > 0.18$), moderate (1500-3000 m; $FiO_2 = 0.18 - 0.15$), severe (3000 - 5000 m; $FiO_2 = 0.15 - 0.11$) and highly severe (> 5000 m; $FiO_2 < 0.11$). Specific physiological and physical responses to hypoxia depend on the hypoxia severity and exposure duration, i.e., the hypoxic dose (Chapman, Karlsen, et al., 2014; Millet et al., 2010). Differences in the hypoxic dose applied have led to differing responses, raising a difficulty in comparing the results of each study (Scott, Slattery, & Dascombe, 2014).

Training camps are usually performed at moderate altitude (Millet et al., 2010), which is considered an optimal level for training purposes (Bonetti & Hopkins, 2009; Wilber et al., 2007). At this altitude, athletes benefit from the hypoxic stimulus, with subsequent performance improvements at sea level, while acute mountain sickness symptoms are likely minimized (Bartsch & Saltin, 2008). Ascent and permanent exposure to higher altitudes can induce health alterations (edema, pulmonary hypertension, etc.), for which an acclimation process is advisable for altitudes higher than 2500 m (Bartsch & Saltin, 2008; Koehle et al., 2014). There are several altitude training centers all over the world, with altitudes ranging between 1200 and 3600 m (Millet et al., 2010) (Table 2). The High Performance Center of Sierra Nevada (Spain, 2320 m), due to its unique location, provides the possibility to alternate training and living at different altitude levels, since it is only 35 minutes apart from sea level.

Table 2. Altitude training places around the world. Adapted from Millet et al. (2010).

Training center	Country	Altitude (m)
Prémanon	France	1200
Thredbo	Australia	1350
Crans-Montana	Switzerland	1500
Albuquerque	USA	1500
Potchefstroom	South-Africa	1550
Snowfarm	New Zealand	1560
Pretoria	South-Africa	1750
Boulder	USA	1780
Ifrane	Morocco	1820
St. Moritz	Switzerland	1820
Font-Romeu	France	1850
Colorado Springs	USA	1860
Kunming	China	1860
Belmeken	Bulgaria	2000
Eldoret	Kenya	2100
Flagstaff	USA	2130
Sierra Nevada	Spain	2320
Iten	Kenya	2350
Addis Ababa	Ethiopia	2400
Bogota	Colombia	2640
Quito	Ecuador	2740
La Paz	Bolivia	3600

1.4.3. Hypoxic training strategies

During the 1968 Mexico Olympic Games, held at an altitude of 2240 m, new world records were established in all the track and field distances up to 800 m, while endurance performance was impaired. The new world records were 1-4% faster than the previous ones (Jokl et al., 1969). These unexpected results aroused interest in the effects of altitude on athletic performance.

Multiple combinations of hypoxia exposure and training exist with the clear aim of enhancing sports performance at sea level or acclimate for competition at altitude (Fig 6). Traditional ‘live high-train high’ (LHTH) strategy usually includes 2 to 4 weeks of altitude training and living, which implies a considerable amount of resources (human, material and economic). Moreover, the higher metabolic stress at altitude forces athletes to reduce their training intensity at the beginning of the stay to progressively increase it later on (Millet et al., 2010). To solve the training intensity problem Levine & Stray-Gundersen (1992) designed the ‘live high-train low’ (LHTL) strategy, allowing athletes to combine the beneficial effects of a prolonged exposure with the maintenance of high intensity trainings throughout the training period. However, all the logistical constraints of this method made it very stressful for athletes. This has motivated the technical development of new devices to simulate altitude (altitude tents, hypoxic sleeping units, hypobaric chambers, hypoxic masks, hypoxic rooms) (Millet et al., 2010). Research is now focusing on the potential of ‘live low-train high’ (LLTH) methods (Girard et al., 2020; Girard et al., 2017), such as intermittent hypoxic exposure at rest (IHE, alternating hypoxia and normoxia), during interval training sessions (IHT) or combined (IHIT, IHE + IHT) to elicit metabolic and neural adaptations. The hypoxic training strategies that have been traditionally focused on the enhancement of endurance are now extended to resistance (RTH) (Martinez-Guardado et al., 2019; Mayo et al., 2018) and repeated sprint ability training (RSH) (Brocherie et al., 2017; Girard et al., 2017; Hamlin et al., 2018).

On the light of emerging evidence on hypoxia, differences between hypoxic types, levels and training strategies should be carefully considered when examining the training adaptive response.

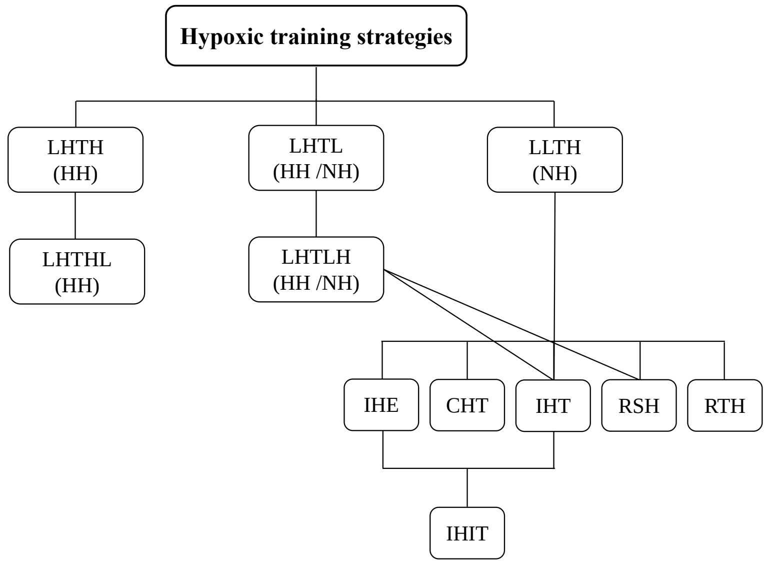


Figure 6. Hypoxic training strategies. Adapted from Girard, Brocherie and Millet (2017). LHTH, 'live high-train-high'; LHTHL, 'live high-train high and low'; LHTL, "live high-train low'; LHTLH, 'live high-train low and high'; LLTH, 'live low-train high'; IHE, intermittent hypoxic exposure; CHT, continuous hypoxic training; IHT, intermittent hypoxic interval training; RSH, repeated sprint training in hypoxia; RTH, resistance training in hypoxia; IHIT, IHE + IHT; NH, normobaric hypoxia; HH, hypobaric hypoxia.

1.4.4. Acute effect of altitude

There is increasing evidence that acute exposure to moderate altitude improves high-velocity sport activities, such as sprints, jumps and throws (Hamlin et al., 2015; Hollings et al., 2012; Levine et al., 2008). Namely, the sprinting performance is improved between 0.2 and 0.7% and the hammer throw and long jump approximately 1% (Hamlin et al., 2015). Likewise, altitudes from 1000 m produce faster times (0.1-0.5%) in sprint distances between 100 and 400 m (Hollings et al., 2012). Generally, performance improves between 0.03 (Mureika, 2000) and 0.12 seconds (Quinn, 2004) for every 1000-m increase in altitude. According to Peronnet et al. (1991) mathematical model, there is a progressive improvement in sprint times for running distances up to 400 m with increasing altitude up to 2500 m and up to 4000 m for distances until 200 m.

Accordingly, the performance of explosive actions in basic strength exercises is enhanced by altitude exposure (Chirosa et al., 2006; Feriche et al., 2014; García-Ramos et al., 2018). Specifically, improvements in squat maximum power and associated load were observed after the ascent to moderate altitude (Chirosa et al., 2006). Likewise, acute exposure to moderate altitude, but not to normobaric hypoxia, led to a ~3% increase in the loading condition associated with peak power output and a ~6% increase in the 1RM assessed during an incremental bench-press test (Feriche et al., 2014). Similarly, moderate altitude elicited greater values of maximal theoretical velocity and power assessed during a loaded SJ force-velocity test and enhanced mechanical performance during unloaded CMJ (García-Ramos et al., 2018). At simulated altitude, however, Scott et al. research (Scott, Slattery, Sculley, & Dascombe, 2018; Scott, Slattery, Sculley, et al., 2015; Scott, Slattery, Sculley, Smith, et al., 2018) did not find any effect of normobaric hypoxia on the performance of strength exercises (squat and deadlift), which is in accordance with Feriche et al. (2014) findings.

Some authors suggest that the altitude-related improvement in explosive actions may be due to a reduction in aerodynamic resistance in approximate proportion to the square of the speed when cycling, running or throwing objects (Hahn & Gore, 2001; Hamlin et al., 2015; Levine et al., 2008). In this sense, athletes competing in events with faster running speeds (e.g. 100 m) are expected to benefit more from the reduced air density associated with altitude (Girard et al., 2017; Hamlin et al., 2015). Increased motor unit recruitment due to a higher reliance on anaerobic metabolism during hypoxia (Balsom et al., 1994; Billaut et al., 2012; Schoenfeld, 2013) could also be partly responsible for the improvements (Feriche et al., 2017). In addition, an increase in spinal excitability has been related to acute simulated hypoxia (Delliaux & Jammes, 2006) and a greater increase in the Hoffmann's reflex amplitude of the soleus muscle has been described at acute moderate altitude when compared with sea level (Tomazin et al., 2016), which can be related to a direct effect of hypoxemia on the supraspinal structures (Feriche et al., 2017).

All these findings seem to indicate a possible additive effect between air pressure and composition that could positively affect explosive actions performed at moderate altitude, while simulated hypoxia does not display changes of interest (Feriche et al., 2014; Scott, Slattery, Sculley, & Dascombe, 2018; Scott, Slattery, Sculley, et al., 2015) and may reproduce different responses (Millet & Debevec, 2020; Millet et al., 2012).

1.4.5. Resistance training under hypoxic conditions

The potential influence of environmental hypoxia on acute and chronic responses to strength training remains largely unexplored. Exposure to higher altitudes generally has been regarded as counterproductive to muscle development (Ferretti et al., 1990; Narici & Kayser, 1995). Loss of muscle mass and its functional capacity has been frequently described (Deldicque & Francaux, 2013; Perrey & Rupp, 2009), although most of the studies were conducted at altitudes higher than the ones commonly used for sport training camps (>5000 m vs. 2000-3000 m). Furthermore, the logistic aspects of high-altitude expeditions significantly differ from altitude training camp settings, where nutrition, sleep and training conditions are carefully controlled.

In this sense, research in the last decade has challenged this dogma (Feriche et al., 2017; Scott, Slattery, & Dascombe, 2014; Scott et al., 2017), suggesting that exposure to moderate hypoxia may help to maximize muscle strength adaptations. Nonetheless, most of the studies were conducted under simulated hypoxic conditions, signaling a paucity of real altitude research.

Hypertrophy-oriented resistance training under hypoxic conditions

The influence of resistance training under hypoxic conditions (RTH) on the development of strength and muscle mass is a research area of current interest (Ramos-Campo et al., 2018). Hypoxic training is known to induce greater muscle oxygen desaturation, increasing the anaerobic metabolism and consequently the production of metabolites (Kon et al., 2010; Kurobe et al., 2015; Schoenfeld, 2013). This higher metabolic stress allows the recruitment of high-threshold motor units (Schoenfeld, 2013; Scott, Slattery, & Dascombe, 2014).

Study results on the morphological and functional responses to RTH are contradictory. Manimmanakorn et al. (2013a; 2013b) applied a low-load RT (20-30% 1RM) with very short inter-set rest periods (30 seconds), while Friedmann et al. (2003) used longer rest intervals (60 seconds). Consequently, Manimmanakorn et al. (2013a; 2013b) observed greater hypertrophic and strength responses after normobaric hypoxic vs. normoxic training, while Friedmann et al. (2003) reported no changes in strength or muscle cross-sectional area after training in both environmental conditions. The same dynamic was verified with studies using moderate loads (70% 1RM or 10RM). Kurobe (2015) and Nishimura (2010) used 60 seconds inter-set rest periods and found enhanced hypertrophic responses compared to normoxic training conditions. Whereas Ho (2014) and Kon (2014) used larger inter-set rest periods (90-120 seconds) and reported no added benefit for training under hypoxia. Furthermore, Scott et al. (2017) observed that adding normobaric hypoxia to moderate-load RT enhanced some physiological responses that are important for muscle development, such as metabolite accumulation or muscle activation. However, there were no changes in physical performance after moderate- (Scott, Slattery, Sculley, & Dascombe, 2018) or high-load RT under normobaric hypoxia (Scott, Slattery, Sculley, Smith, et al., 2018). Finally, Inness et al. (2016) analyzed the effects of a heavy RT program and found a large improvement in absolute and relative strength, as well as 1RM under hypoxia vs. normoxia.

It is likely that hypoxia-mediated increases in metabolic stress may only be induced when using relatively brief inter-set rest periods (Feriche et al., 2019; Scott, Slattery, & Dascombe, 2014, 2015), typically applied in moderate but not high-load training protocols. It has been hypothesized that recovery times longer than 90 s could attenuate the metabolic stress, allowing phospho-creatine resynthesis and the removal of metabolites from the muscle before the subsequent set (Scott, Slattery, Sculley, et al., 2015), matching the RT effects in hypoxia and normoxia.

A recent meta-analysis concluded that RTH did not add benefits for muscle size and strength compared to the same training in normoxia (Ramos-Campo et al., 2018). However, according to this study (Ramos-Campo et al., 2018), differences in research methodologies (populations, training protocols, muscles involved, hypoxic dose) difficult the comparison between studies and do not allow to draw firm conclusions. Moreover, it would be important to assess if real altitude shows similar results, since it has been suggested that altitude is a more severe environmental condition that leads to different physiological adaptations (Millet & Debevec, 2020; Millet et al., 2012).

Power-oriented resistance training under hypoxic conditions

RT aiming to enhance athletic performance should provide both structural and neural adaptations (Suchomel et al., 2018). However, most of the research on the RTH has been focused on hypertrophy-oriented training (Ramos-Campo et al., 2018) without studying the altitude training effect on explosive muscle performance. The lack of longitudinal studies analyzing the potential specific effects of altitude training on muscle power performance is even more surprising considering that acute ascent to moderate altitude seems to improve explosive performance (García-Ramos et al., 2018; Levine et al., 2008).

Emerging evidence supports the use of moderate altitude training to improve leg extension power capacity at sea level (Feriche et al., 2017), whilst doubts remain as to the principal mechanisms involved (Feriche et al., 2017; Millet et al., 2012). Specifically, altitude training increased the SJ mean peak power and PV in 7.8 and 4.4% after 2 weeks (García-Ramos et al., 2014) and the SJ height and swimming start performance in 7.2 and 2.8% after 17 days (García-Ramos, Padial, et al., 2016), although there was not a control group in both studies. García-Ramos, Padial, et al. (2016) also found an inverse correlation between the percentages of change in SJ height and swimming start time ($r = -0.47$ to -0.73). García-Ramos, Stirn, et al. (2016) did not report differences between environmental conditions after a 3-week concurrent training in SJ performance, despite a slight improvement in PV after both training periods. In addition, no changes in swimming start times were reported at altitude, while an impairment was registered at sea level, displaying differences between conditions. The authors pointed the need for further studies where a power-oriented RT should be applied to assess if altitude training has an additional benefit on the development of explosive actions when compared to sea-level training. In this sense, Morales-Artacho et al. (2018) applied a 4-week power-oriented

RT at altitude but under an intermittent strategy (LLTH). A main effect of time on F_0 and P_{max} was reported ($p < 0.05$, $\eta^2_G > 0.04$), as well as a main effect of training group on P_{max} ($p = 0.037$, $\eta^2_G = 0.17$), due to greater values displayed by the altitude group compared to the normoxia group.

All these findings seem to indicate that altitude training may improve the performance of high-speed actions, which can be useful to improve velocity and technical skills in power-related sports (Feriche et al., 2017).

1.5. Statement of the problem

The literature review highlights the need for further research in RTH area, since there is no consensus on the beneficial influence of hypoxic training conditions on muscle functional and physiological adaptations, especially when real altitude is used. Specifically, the influence of hypobaric hypoxia on power-oriented RT remains unexplored and sets the main objective of this thesis. To date, no research has investigated the effects of altitude training on technical and physical performance in judokas, or the evolution of those effects after returning to sea level. Moreover, although the leg extension action has been considered a fundamental parameter in the technical performance of *ippon-seoi-nage*, transference from physical improvements to technical performance in judo has not been examined before. Therefore, a comprehensive research on power-oriented RT at altitude is required to determine the efficacy of this novel training strategy on physical and technical aspects of high-level judokas.

1.6. Aims and hypothesis

The primary aim of this doctoral thesis was to analyze the effect of a power-oriented RT program at moderate altitude on the leg extension capacity, on the technical performance of the *ippon-seoi-nage* and on the relationship between them in elite judokas. Specifically, this research thesis aimed to:

1. Investigate the effect of acute exposure to moderate altitude on leg push capacity (PV, 1RM and load-velocity relationship) in elite judokas. It was hypothesized that acute altitude exposure would improve the CMJ outputs.

2. Determine success criteria and mechanical parameters to improve *ippon-seoi-nage* learning process. It was hypothesized that (1) a general technique pattern would be performed by elite judokas (high intra-group reliability) and (2) the reliability analysis would disclose reliable variables that could be considered as success criteria for the *ippon-seoi-nage*.

3. Investigate the effect of acute exposure to moderate altitude on kinematic variables of the *ippon-seoi-nage* in elite judokas. It was hypothesized that both, the altitude effect on leg extension capability and on the kinematic variables of the *ippon-seoi-nage* would improve the performance of this technique.

4. Explore the effect of a power-oriented RT at moderate altitude on the PV, 1RM and load-velocity relationship (L_0, V_0 and S_{lv}) of the lower-limbs in elite judokas. It was hypothesized that altitude training would improve CMJ outputs.

5. Assess the effect of a power-oriented RT program at moderate altitude on the P_{max}, current and optimal lower-limb F-V (F_0, V_0 and S_{fv}) profile of elite judokas. It was hypothesized that (1) the training intervention at moderate altitude would improve the P_{max} and (2) reduce the imbalance between the current and optimal F-V profile.

6. Investigate the effect of a power-oriented RT program at moderate altitude on the times and acceleration variables of the *ippon-seoi-nage* in elite judokas. It was hypothesized that both, the altitude training effect on leg extension capacity and on the

kinematic variables of the *ippon-seoi-nage* would improve the performance of this technique.

7. Determine the effect of a power-oriented RT program at moderate altitude on body composition of elite judokas. It was hypothesized that the training intervention at moderate altitude would not produce any changes in body composition.

8. Analyze the association between the leg extension capacity (PV, 1RM, F_0, V_0 and P_{max}) and the technical performance of the *ippon-seoi-nage* (Max2_accelT and Max2_gyroT) in elite judokas, as well as the impact of ascent and training at moderate altitude on this association. It was hypothesized that (1) the CMJ variables would correlate with the kinematic variables of the *ippon-seoi-nage* and (2) this association would not be affected by the ascent or training at moderate altitude.

2 Methods

2.1. Experimental design

A longitudinal design, with intra- and inter-group measurements, was used to compare the effect of a lower-limb power-oriented RT at moderate altitude (hypobaric hypoxia) or sea level (normoxia) on leg extension capacity, on kinematic variables of the *ippon-seoi-nage* and on the relationship between them in elite judokas. Participants were randomly assigned to a group that performed a 3-week training program at hypobaric hypoxia (at the High Performance Center of Sierra Nevada, 2320 m; HT; *n* = 13) or normoxia (at the Spanish Judo Training Center of Valencia, 15 m; NT; *n* = 11) (Fig 7).

Figure 7. High Performance Center of Sierra Nevada and Spanish Judo Training Center of Valencia.

Testing sessions were conducted under normoxic conditions at 4 time-points: pre-test (N1), post-test (N2), one and two weeks after training (N3 and N4, respectively). The HT undertook an additional testing session in acute hypoxia (H1) conditions immediately after the ascent to altitude. An intra-group design was used to assess the effect of acute exposure to moderate altitude on the same variables (N1 vs. H1). All tests were performed at the same time of the day, at ~22˚C and ~60% humidity for the normoxic tests and ~28% humidity for the hypoxic test (Fig 8).

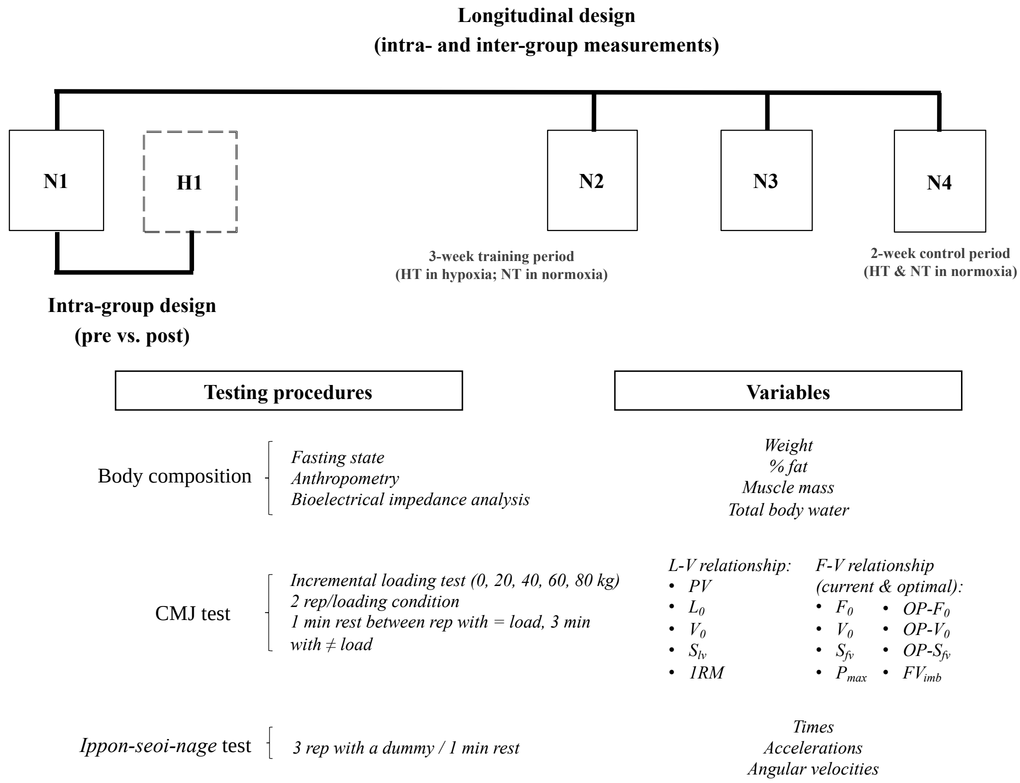


Figure 8. Experimental design.

2.2. Participants

Twenty-four male judokas from the Spanish Judo Training Center of Valencia (age: 22.04 ± 3.18 years; body mass: 84.54 ± 19.17 kg; height: 179.36 ± 9.84 cm; fat percentage: 11.83 ± 3.28%) participated in this study. The study was carried out at the end of a special preparation mesocycle. All participants had experience in the loaded CMJ and in the protocol used in this study; they had been practicing judo for at least 10 years. Their technical level ranged from first to third Dan black belt and all of them have been medalists in junior or senior National Championships in Spain, Dominican Republic or Georgia; five of them in junior or senior European Cups; eight of them in junior or senior European Cups; four in Continental Opens; one in Grand Prix; two in junior Continental Championships; and one in junior World Championships. They reported no chronic diseases or recent injuries that could compromise performance. Participants were instructed to avoid any strenuous exercise for a minimum of two days preceding the testing sessions. They were informed about the study protocol and signed a written informed consent form prior to investigation. The study protocol was approved by the university Institutional Review Board and was in accordance with the Declaration of Helsinki.

2.3. Procedures

2.3.1. Body composition evaluation

Judokas undertook a body composition assessment after an overnight fasting, in N1 and N3 testing sessions (Fig 9). It included anthropometric measurements of body mass (scales, Tanita BC 418 Segmental, Tokyo, Japan), height (stadiometer, Seca 202, Seca Ltd., Hamburg, Germany), skinfolds (skinfold caliper, Holtain Ltd., Crymych, UK) and mid-thigh circumference (flexible, non-elastic metallic anthropometric tape measure, Holtain Ltd., Crymych, UK). Skinfolds (triceps, subscapular, supraspinal, abdominal) values were used to determine fat percentage (Faulkner, 1968). The extended lower limb length (distance from the great trochanter to toes with maximal plantar flexion) was measured to calculate the push-off distance needed for Samozino's method (Samozino et al., 2008). Additionally, bioelectrical impedance analysis was carried out using the standard four- pole technique, with single-frequency at 50 kHz sampling rate (BIA 101 Anniversary Sport Full, Realmet Institute, Barcelona, Spain) (Mascherini et al., 2015; Meleleo et al., 2017). Participants were evaluated in supine position and the electrodes placed on the dorsal surface of right foot and ankle, and right wrist and hand. Total body water, body cellular mass, muscle mass and angle phase were determined. All the anthropometric procedures were carried out by a trained investigator following the standard techniques proposed by the International Society for the Advancement of Kinanthropometry.

Figure 9. Body composition evaluation.

2.3.2. Countermovement jump test

After a 10-minute standardized warm-up (jogging, dynamic stretching, joint mobility exercises, unloaded CMJs, and 5 CMJs loaded with 20 kg), participants undertook an incremental loaded CMJ test (Fig 10).

Figure 10. Countermovement jump test.

The protocol consisted of 2 repetitions per each loading condition (20, 40, 60 and 80 kg), separated by 1 minute of rest between repetitions with the same load and 3 minutes between different loading conditions. Participants performed the CMJ technique by standing with the knees and hips fully extended, feet approximately shoulder-width apart and the bar resting at the level of the acromion across the back. They were instructed to jump as high as possible after performing a countermovement to 90˚ of knee flexion. A manual goniometer was used to measure the 90˚ angle for each participant and an adjustable rod on a tripod was set with that individual height (Fig 11). In order to ensure the 90˚ knee flexion participants had to touch the rod with their glutei (Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, & Feriche, 2018). The vertical distance between the greater trochanter and ground with knees flexed at 90º was measured to calculate the push-off distance needed for Samozino's method (Samozino et al., 2008). The individual value of push-off distance for each participant was maintained for all trials.

Figure 11. Measurement of the knee 90 ° angle with a manual goniometer.

Load-velocity relationship

The CMJ test was performed in a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain) with a linear velocity transducer (T-Force System, Ergotech, Murcia, Spain) at 1000 Hz sampling rate attached to the bar. The PV and the MPV of each jump were recorded. The repetition with the highest PV of each load was selected and used for analysis. The relationship between load displaced and PV was established by fitting first-order-polynomials to the data (load-velocity relationship). PV associated to the load displacement equivalent to the 25, 50, 75 and 100% of the judoka's body mass (PV25%BM, PV50%BM, PV75%BM and PV100%BM, respectively) was calculated through a regression equation. The 1RM was considered as the absolute load linked to a MPV of 0.33 $m \cdot s^{-1}$ obtained from the individual load-velocity relationship (Conceição et al., 2016; Loturco et al., 2016). Afterwards, the 1RM relative to body mass ($kg \cdot kg^{-1}$ BM) was calculated. The V_0, maximal theoretical load (L_0) and load-velocity relationship slope ($S_{lv} = - L_0/V_0$) were subsequently determined using the peak values of velocity measured for each loading condition. Test-retest reliability of this test has been previously reported (García-Ramos et al., 2017).

Force-velocity relationship

Simultaneously, Samozino's method (Samozino et al., 2008) was used to assess the mechanical outputs under the above mentioned four individual loading conditions, plus a loading condition of 0.2 kg (free jump with a plastic bar to maintain the same body position). For this, CMJ height was estimated from the flight time collected by an infrared platform (Optojump, Microgate, Bolzano, Italy) at a 1000 Hz sampling rate. The CMJ height with 0.2 kg was considered the jump height (JH), indicating the jumping performance. The mean values of force, velocity and power at each loading condition were calculated from the equations proposed by Samozino et al. (2008) and validated for CMJ (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017). Test-retest reliability of this test has been previously reported (Jiménez-Reyes, Samozino, Pareja-Blanco, et al., 2017). Afterwards, these mean values were used to assess the current F-V relationship and the associated slope (S_{fv} = - F_0/V_0), maximum theoretical force (F_0, force-axis intercept), velocity (V_0, velocity-axis intercept) and power ($P_{max}= F_0 \cdot V_0/4$) values through a linear regression. A specific spreadsheet based on the equations validated by Samozino et al. (2008) was used for this calculation. The optimal profile (i.e., the ideal profile that would maximize jump height for a given athlete, OP-S_{fv}) and associated F_0 (OP-F_0) and V_0 (OP-V_0), as well as the F-V imbalance (i.e., relative difference between individual current and optimal F-V profiles, FV_{imb} in %) were also automatically estimated from the same spreadsheet (Morin & Samozino, 2016; Samozino et al., 2014).

2.3.3. *Ippon-seoi-nage* test

Afterwards, participants performed a specific warm-up (5 *ippon-seoi-nage* repetitions) to prepare for the technique test. To ensure stable execution conditions during all the assessments, avoiding potential *uke*'s body mass variation or technique facilitation, a dummy was used as an *uke* (57 kg of mass). The technique test began after 3 minutes of rest and included 3 repetitions of the *ippon-seoi-nage* with 1 minute of rest between attempts. To perform this technique the judoka had to pull the dummy's *judogi* to take it off-balance, turning to position himself underneath the dummy before finally throwing it over his shoulder (Fig 12). The judoka's starting position was standing with feet shoulder-width apart, gripping the dummy's *judogi*.

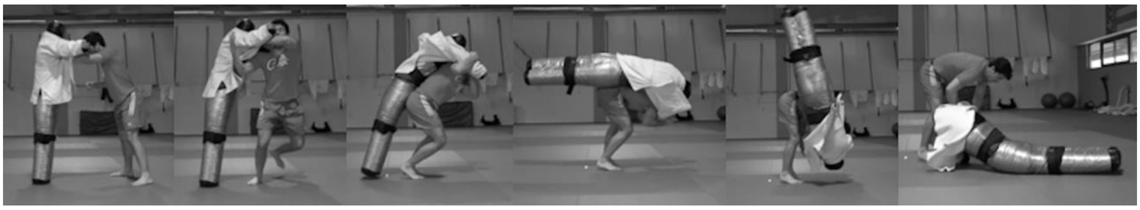


Figure 12. *Ippon-seoi-nage* sequence. 1) Starting position; 2) beginning of the repetition; 3) off-balance; 4) loading the dummy onto the back, reaching the dummy's horizontal position and leg extension; 5) dummy's flight over the judoka; 6) end of the repetition.

Kinematic variables transferred to the *uke* during the *ippon-seoi-nage* test were assessed by using a wearable sensor (Wimu, Realtrack System, Almería, Spain) placed on the back of the dummy. The sensor was fixed with a belt at waist height (Fig 13). This placement was considered as the center of mass and ensured that the sensor was protected from direct impact from the *tori* or the floor.

Figure 13. Placement of the wearable sensor.

The device analyzed acceleration (G) and angular velocity (rad·s^{-1}) in the three axes (*x* or longitudinal axis, *y* or transversal axis and *z* or anterior-posterior axis) at a 1000 Hz sampling rate (Fig 14). The beginning of the repetition was defined as the time when the dummy started to become unbalanced (i.e., the angular velocity in the *y* axis deviates from the baseline with a permanent change of at least 50 ms). Three peaks of the resultant acceleration (AccelT) were determined, the first related to the off-balance (Peak1_accelT), the second to the tori's leg extension (Peak2_accelT) and the third to the dummy's impact on the ground (Peak3_accelT) (Fig 14A). In addition, three peaks of the resultant angular velocity (GyroT) were assessed, the first related to pulling the dummy off balance (Peak1_gyroT), the second to the dummy's flight over the *tori* (Peak2_gyroT) and the third to the end of the repetition (Peak3_gyroT). Lastly, the inflection point on the angular velocity of the *y* axis normalized (GyroYnormalized) was assessed and associated to the dummy's horizontal position (Fig 14B).

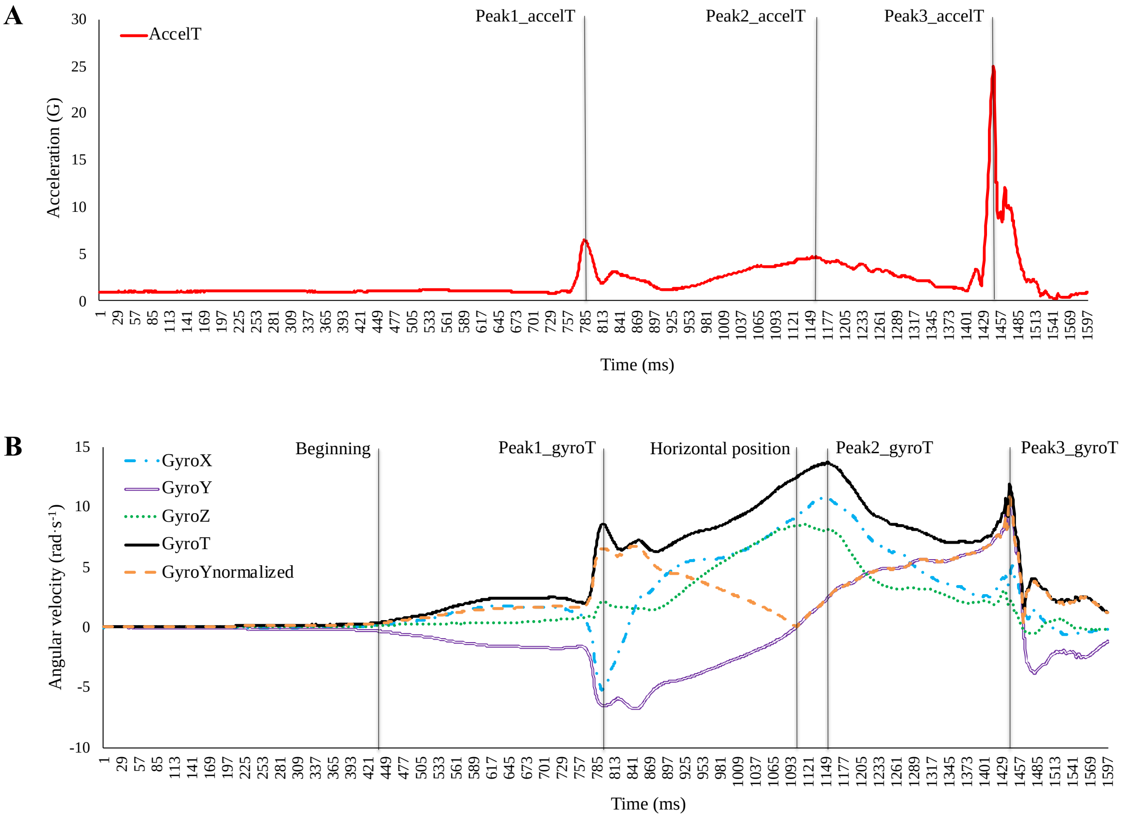


Figure 14. Representation of the resultant acceleration (AccelT) (A), angular velocity in the three axes (GyroX, GyroY and GyroZ) and resultant angular velocity (GyroT) (B) of the *ippon-seoi-nage* performed by one judoka. Three landmarks of the AccelT (Peak1_accelT, Peak2_accelT and Peak3_accelT) and of the GyroT (Peak1_gyroT, Peak2_gyroT and Peak3_gyroT) are displayed. The beginning of the repetition (considering the baseline of the GyroY) and the dummy's horizontal position (represented by the inflection point on the GyroYnormalized) are also displayed.

The studied variables were organized as (1) time variables: time to reach the first, second and third peak of the resultant acceleration (Tpeak1_accelT, Tpeak2_accelT and Tpeak3_accelT, respectively), time to reach the first, second and third peak of the resultant angular velocity (Tpeak1_gyroT, Tpeak2_gyroT and Tpeak3_gyroT, respectively) and time to reach the dummy's horizontal position (Thor); (2) acceleration variables: values of resultant acceleration in the first (Max1_accelT), second (Max2_accelT) and third (Max3_accelT) peaks; and (3) angular variables: values of resultant angular velocity in the first (Max1_gyroT), second (Max2_gyroT) and third (Max3_gyroT) peaks.

A video camera (Casio EX-F1, Tokyo, Japan) was used to record the technical testing sessions at a 250 Hz sampling rate. Two experienced coaches rated the 3 *ippon-seoi-nage* repetitions based on the technical model approach of the Kodokan School (Daigo, 2005). Thus, 4 items were defined to evaluate the technique (*kuzushi*, *tsukuri*, *kake* and technique-flow) and 1 success criterion was associated to each item (Fig 15). Each of these criteria could be scored as follows: 1 (very bad), 2 (bad), 3 (good) and 4 (very good). The two best repetitions were selected for motion and reliability analysis. Afterwards the repetition with the lowest Thor was chosen as the best repetition for further analysis.

Items	**Success criterion**	**Score (1, 2, 3, 4)**		
		Trial 1	**Trial 2**	**Trial 3**
Kuzushi	Angle between the *uke* and the ground at the moment of the *tsukuri* (90º-45º)			
Tsukuri	Angle of knee flexion of the *tori* before lifting the *uke* (180º-90º)			
Kake	Angle between the *tori*'s chest and the ground when *uke* touches the ground (90º-0º)			
Technique-flow	Fluid sequence of the *kuzushi*, *tsukuri* and *kake*			
Total				

Figure 15. Evaluation sheet for *ippon-seoi-nage*. Scores: 1 (very bad), 2 (bad), 3 (good) and 4 (very good).

2.4. Training program

The 3-week training program included a physical conditioning session in the morning and a judo session in the afternoon, from Monday to Saturday morning. During the experimental period, the researchers filled a training diary, collecting data related to the session aim, duration, perceived exertion (RPE) and loading conditions, as well as a weekly weigh-in. Within 30 minutes after each session, a category RPE scale ranging from 0-10 (Foster et al., 2001) was used to assess training intensity (Table 3). Participants performed 14 judo sessions during the training camp (Fig 16). Those sessions were designed by the coaches, keeping the same exercises, volume and intensity in both training sites. The judo training intensity was reduced in the HT in the first week and progressively increased to reach the same intensity as NT in the third week (RPE between 6 and 6.5; $p = 0.127$).

Figure 16. Judo training sessions.

Physical conditioning sessions included 8 power-oriented resistance sessions (Fig 17) alternated with 7 metabolic sessions. The content of the physical conditioning sessions was designed and supervised by the research team and is fully detailed in the Appendix 1. The power-oriented resistance training sessions included 2 parts: a velocity-based training and a contrast training (contrast between moderate- to high-load RT exercise and low-load specific exercise performed at maximal intended velocity). In the first part, judokas performed 4-6 sets of 6 CMJ at a monitored velocity, with 4 minutes of rest. The training load displaced during all CMJs (~35-40% 1RM) was estimated from the load linked to 1.2 $m \cdot s^{-1}$ of the MPV from the individual load-velocity relationship

(Pérez-Castilla et al., 2020). For this, a linear regression model was fitted each Monday after the warm-up and used to estimate the external load corresponding to a barbell MPV of 1.2 $m \cdot s^{-1}$. Wednesdays and Fridays' training load was estimated during pre-test (N1), which allowed the participants to improve the velocity as their leg extension capacity increased in both study conditions. In the second part, athletes performed 3-4 sets of 2 repetitions of a moderate- to high-load RT exercise (thruster 70% 1RM on Mondays, ½ squat 90% 1RM on Wednesdays and sumo-deadlift-high-pull 70% 1RM on Fridays) followed by 6 repetitions of a low-load specific judo exercise (*ippon-seoi-nage* throws), with 4 minutes of rest. Metabolic sessions comprised a circuit-training of high, medium or low intensity, as well as compensatory exercises. The circuit-training included 4-12 functional and/or technical exercises, organized in a continuous (20 minutes) or intermittent structure (3-4 blocks x [12:8 to 40:20 work:rest ratio], 3-5 minutes inter-block rest). Both groups showed similar RPE values in the resistance ($p = 0.860$) and metabolic sessions ($p = 0.953$) (Table 3). The mean duration of the sessions was similar between groups and was 105.01 ± 16.58 minutes for the judo sessions and 78.29 ± 4.45 minutes for the physical conditioning sessions.

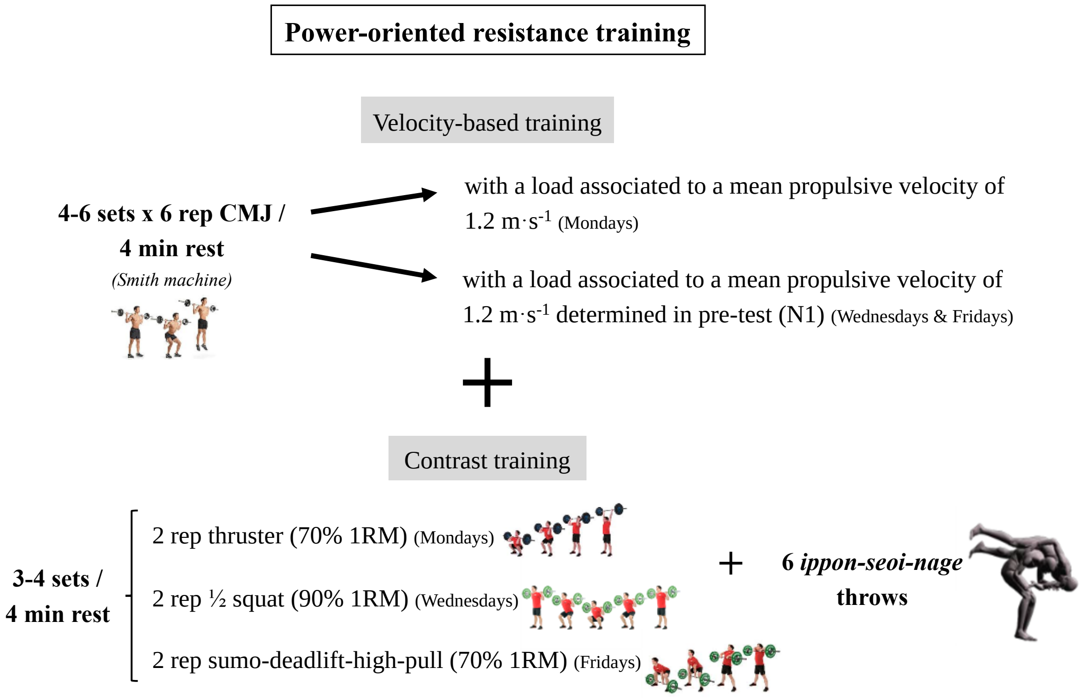


Figure 17. Power-oriented resistance training.

After the training camp there were 2 training-controlled weeks. During this period, both groups trained together in the Spanish Judo Training Center of Valencia, completing 10 judo sessions and 9 physical conditioning sessions (7 resistance and 2 metabolic sessions). The mean duration of these sessions was 114.92 ± 9.44 minutes for the judo and 78.56 ± 2.87 minutes for the physical conditioning sessions. No differences in RPE were found during the post-training camp period between groups (Table 3).

Table 3. Rating of perceived exertion (RPE) in the training and post-training period in both groups.

		HT	NT	p [95% CI]	ES
Training period	RPE-RT	5.51 ± 0.89	5.46 ± 0.66	0.860 [-0.602, 0.715]	-0.065
	RPE-MT	6.67 ± 0.65	6.65 ± 0.47	0.953 [-0.506, 0.478]	0.036
	RPE-PCT	6.06 ± 0.54	6.08 ± 0.64	0.924 [-0.477, 0.523]	-0.023
	RPE-JudoT	6.01 ± 0.59	6.78 ± 0.49	0.003 [0.295, 1.232]	-1.426
Post-training period	RPE-PCT	6.05 ± 0.64	6.40 ± 0.83	0.303 [-0.337, 1.03]	-0.477
	RPE-JudoT	6.88 ± 0.83	7.10 ± 0.40	0.440 [-0.365, 0.807]	-0.358

RPE-RT – mean RPE of the resistance training; RPE-MT – mean RPE of the metabolic training; RPE-PCT – mean RPE of the physical conditioning training; RPE-JudoT – mean RPE of the judo training. HT: hypobaric hypoxia training group; NT: normoxia training group. p [95% CI]: p-value with the corresponding 95% confidence interval; ES: effect size (Cohen's d standardized mean differences).

2.5. Statistical analysis

Data are presented as mean ± standard deviation (SD). Normal distribution of the data was confirmed using a Shapiro-Wilk test.

A two-factor mixed ANOVA was used to assess the effects of time (within-participants factor: N1 vs. N2 vs. N3) and altitude (between-participants factor: HT vs. NT) on kinematic variables of the *ippon-seoi-nage*, body composition and leg extension mechanical variables. A complementary mixed model was used to assess the effects of time (within-participants factor: N1 vs. N4) and altitude (between-participants factor: HT vs. NT) on the same variables. This comparison was performed separately to prevent that the sample size reduction in N4 affected the ANOVA's results if 4 levels of the time factor were included. Effect sizes through the partial eta-squared (η^2_p) value and thresholds (0.02 [small], 0.13 [medium] and 0.26 [large]) were calculated along with ANOVA effects (Bakeman, 2005). A one factor ANOVA test was used to compare, week to week, the CMJ's training load, RPE and session duration between both groups. Pre-post differences in all previous variables were assessed separately in each group via a mean comparison test. Standardized differences (i.e., Cohen's d effect sizes and thresholds: > 0.2 [small], > 0.6 [moderate], > 1.2 [large] and > 2 [very large]) were also calculated (Hopkins et al., 2009).

Correlation analysis between the kinematic variables of the *ippon-seoi-nage* and the leg extension mechanical variables were assessed through a Pearson correlation coefficient (*r*) in each group (HT and NT) and time-point (N1, H1 and N2). The correspondent Fisher's Z-transformed *r* coefficient was compared between different time-points (N1 vs. N2 and N1 vs. H1).

Between-repetition reliability of the *ippon-seoi-nage* kinematic variables was assessed by the within-subjects coefficient of variation (CV) and intra-class correlation coefficient (ICC) with their respective 95% confidence intervals in N1 and H1. Additionally, the between-subjects CV and the individual CV were also calculated for each variable. An acceptable variability was defined as a CV < 15% and an ICC > 0.70 (Haff et al., 2015). To interpret the magnitude of differences observed between the CVs from the 2 testing conditions (N1 vs. H1) a criterion for the smallest important ratio was established as higher than 1.15 (Fulton et al., 2009).

The reliability analysis was performed by means of a custom spreadsheet (Hopkins, 2000). SPSS software version 24.0 (IBM SPSS, Chicago, IL, USA) was used for all the other analyses. Statistical significance was set at an alpha level of 0.05.

3 Results

3.1. Effect of acute exposure to moderate altitude

3.1.1. Leg extension mechanical variables

Figure 18 shows the comparative analysis results of the PV between N1 and H1. Small increments in PV were reached during the loaded CMJ test in H1 conditions (3.67%; $p < 0.05$) (Fig 18). No differences in 1RM relative to body mass and in the load-velocity relationship determined using peak values of velocity (L_0, V_0 and S_{lv}) were observed by the ascent to moderate altitude ($p > 0.05$) (Table 4).

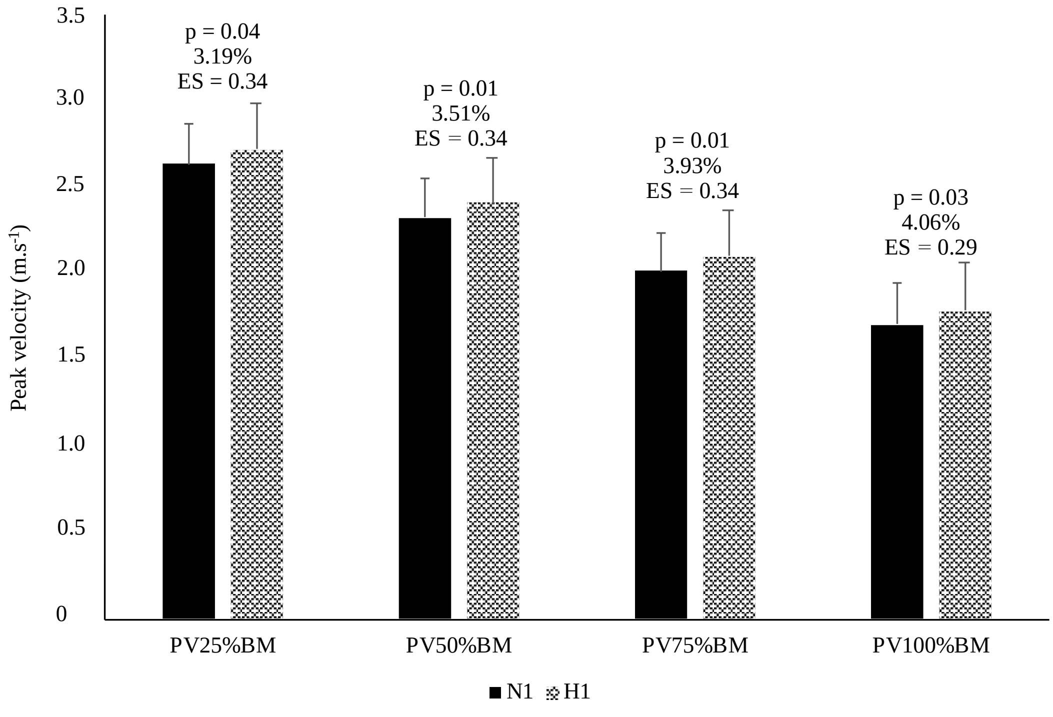


Figure 18. Acute effect of hypoxia on the leg extension peak velocities. Mean ± SD. PV25%BM, PV50%BM, PV75%BM and PV100%BM, peak velocity with 25, 50, 75 and 100% of the judoka's body mass, respectively; N1: normoxia test; H1: hypoxia test; p: p-value; the magnitude of differences was expressed as standardized mean differences (Cohen's effect size, ES) and as percentage of change; no significant differences between N1 and H1.

Table 4. Acute effect of hypoxia on the maximal dynamic strength and the load-velocity profile.

	N1	H1	p	ES
1RM ($kg \cdot kg^{-1}$)	1.86 ± 0.31	1.87 ± 0.37	0.86	0.02
V_0 ($m \cdot s^{-1}$)	2.95 ± 0.24	3.00 ± 0.29	0.245	0.20
L_0 (kg)	207.48 ± 30.09	217.92 ± 36.67	0.143	0.31
S_{lv} ($kg \cdot s \cdot m^{-1}$)	-71.117 ± 14.657	-73.600 ± 16.568	0.441	-0.16

1RM: maximal 1 repetition relative to body mass. V_0: maximal theoretical velocity; L_0: maximal theoretical load; S_{lv}: load-velocity relationship slope; N1: normoxia test; H1: hypoxia test; p: p-value; ES: Cohen's effect size; no significant differences between N1 and H1.

3.1.2. Reliability of the *ippon-seoi-nage* kinematic variables

Tables 5 and 6 show the reliability of the *ippon-seoi-nage* kinematic variables in N1 and H1 conditions, respectively. The time, acceleration and angular variables displayed a good individual reliability in both conditions [CV = 8.46% (ranged from 4.58 to 12.83%) in N1; CV = 8.37% (ranged from 4.2 to 14.4%) in H1]. However, within-subject reliability remained within the standard minimum references (CV < 15% and ICC > 0.70) only in one of the time variables (Tpeak2_accelT), one of the acceleration variables (Max1_accelT) and one of the angular variables (Max1_gyroT) in N1 and in four of the time variables (Tpeak1_accelT, Tpeak3_accelT, Tpak1_gyroT and Thor) and two of the angular variables (Max 1_gyroT and Max2_gyroT) in H1.

Table 5. Reliability of the kinematic variables of the *ippon-seoi-nage* in normoxia (N1) condition.

	Repetition 1	Repetition 2	p	ES	Within-subjects CV (95% CI)	ICC (95% CI)	Between-subjects CV	Individual CV
Tpeak1_accelT (ms)	409.85 ± 79.22	423 ± 97.57	0.66	0.15	17.58 (12.61, 29.02)	0.35 (-0.22, 0.74)	21.23	10.87
Tpeak2_accelT (ms)	898.46 ± 132.55	933.08 ± 115.84	0.19	0.28	6.9 (4.94, 11.38)	0.78 (0.41, 0.93)	13.56	6.36
Tpeak3_accelT (ms)	1194.54 ± 99.36	1219.08 ± 115.8	0.47	0.23	6.92 (4.96, 11.42)	0.43 (-0.13, 0.79)	8.91	4.58
Max1_accelT (G)	6.1 ± 1.33	6.38 ± 1.86	0.44	0.17	14.25 (10.22, 23.53)	0.73 (0.33, 0.91)	25.58	12.14
Max2_accelT (G)	3.03 ± 0.83	2.75 ± 0.75	0.17	-0.36	17.52 (12.56, 28.92)	0.63 (0.15, 0.87)	27.4	12.83
Tpeak1_gyroT (ms)	431.85 ± 94.09	444.54 ± 101.76	0.67	0.13	16.94 (12.15, 27.97)	0.46 (-0.09, 0.8)	22.35	10.43
Tpeak2_gyroT (ms)	865.85 ± 130.43	908.31 ± 118.71	0.22	0.34	9.46 (6.78, 15.61)	0.59 (0.08, 0.85)	14.04	7.3
Tpeak3_gyroT (ms)	1173.92 ± 109.41	1197.15 ± 102.74	0.53	0.22	7.64 (5.48, 12.62)	0.3 (-0.28, 0.72)	8.95	5.2
Max1_gyroT (rad·s^{-1})	6.87 ± 1.02	7.10 ± 1.63	0.45	0.17	10.71 (7.68, 17.68)	0.73 (0.33, 0.91)	18.98	6.94
Max2_gyroT (rad·s^{-1})	10.35 ± 1.42	10.03 ± 1.36	0.41	-0.23	9.54 (6.84, 15.75)	0.55 (0.02, 0.84)	13.61	6.73
Thor (ms)	859 ± 122.18	896.15 ± 112.71	0.42	0.32	13.03 (9.35, 21.51)	0.06 (-0.49, 0.57)	13.38	9.73

p, p-value; ES, Cohen's effect size; CV, coefficient of variation; ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval; Tpeak1_accelT, Tpeak2_accelT and Tpeak3_accelT, time to reach the first, second and third peak of the resultant acceleration, respectively; Tpeak1_gyroT, Tpeak2_gyroT and Tpeak3_gyroT, time to reach the first, second and third peak of the resultant angular velocity, respectively; Max1_accelT and Max2_accelT, values of resultant acceleration that correspond to the peaks; Max1_gyroT and Max2_gyroT, values of resultant angular velocity that correspond to the peaks; Thor, time to reach the dummy's horizontal position.

Table 6. Reliability of the kinematic variables of the *ippon-seoi-nage* in hypoxia (H1) condition.

	Repetition 1	Repetition 2	p	ES	Within-subjects CV (95% CI)	ICC (95% CI)	Between-subjects CV	Individual CV
Tpeak1_accelT (ms)	405.31 ± 89.22	405.92 ± 83.85	0.97	0.01	10.74 (7.7, 17.73)	0.78 (0.42, 0.93)	21.33	9.06
Tpeak2_accelT (ms)	905.69 ± 151.13	891 ± 175.13	0.76	-0.09	13.54 (9.71, 22.35)	0.48 (-0.07, 0.81)	18.16	9.51
Tpeak3_accelT (ms)	1190.46 ± 153.29	1210.38 ± 162.38	0.54	0.13	6.71 (4.81, 11.07)	0.77 (0.41, 0.92)	13.15	5.14
Max1_accelT (G)	6.88 ± 1.62	6.97 ± 2.1	0.89	0.04	21.26 (15.25, 35.1)	0.41 (-0.15, 0.78)	26.8	13.04
Max2_accelT (G)	2.84 ± 1.09	2.56 ± 0.93	0.28	-0.28	23.29 (16.7, 38.45)	0.65 (0.18, 0.88)	37.4	14.4
Tpeak1_gyroT (ms)	419.15 ± 102.11	424.23 ± 103.46	0.78	0.05	10.72 (7.69, 17.69)	0.83 (0.54, 0.95)	24.37	9.32
Tpeak2_gyroT (ms)	903.77 ± 148.39	864.38 ± 132.69	0.28	-0.28	10.14 (7.27, 16.73)	0.63 (0.15, 0.87)	15.9	8.02
Tpeak3_gyroT (ms)	1149.77 ± 163.94	1180.08 ± 146.76	0.49	0.19	9.25 (6.64, 15.28)	0.56 (0.04, 0.84)	13.34	6.06
Max1_gyroT (rad·s^{-1})	6.99 ± 1.22	6.93 ± 1.17	0.68	-0.05	5.29 (3.79, 8.73)	0.92 (0.76, 0.98)	17.14	4.2
Max2_gyroT (rad·s^{-1})	10.20 ± 1.92	10.01 ± 1.55	0.63	-0.11	10.03 (7.19, 16.56)	0.7 (0.27, 0.9)	17.16	6.75
Thor (ms)	878.85 ± 175.44	879.23 ± 180.12	0.99	0	8.82 (6.32, 14.56)	0.84 (0.55, 0.95)	20.22	6.55

p, p-value; ES, Cohen's effect size; CV, coefficient of variation; ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval; Tpeak1_accelT, Tpeak2_accelT and Tpeak3_accelT, time to reach the first, second and third peak of the resultant acceleration, respectively; Tpeak1_gyroT, Tpeak2_gyroT and Tpeak3_gyroT, time to reach the first, second and third peak of the resultant angular velocity, respectively; Max1_accelT and Max2_accelT, values of resultant acceleration that correspond to the peaks; Max1_gyroT and Max2_gyroT, values of resultant angular velocity that correspond to the peaks; Thor, time to reach the dummy's horizontal position.

The within-subjects CV ratio between H1 and N1 indicates that some variables were more reliable in N1 (Tpeak2_accelT [CV ratio = 1.96]; Max1_accelT [CV ratio = 1.49]; Max2_accelT [CV ratio = 1.33] and Tpeak3_gyroT [CV ratio = 1.21]). Only two of the eleven CV ratios exceeded the individual CV ratio of 1.15 (Tpeak2_accelT [CV ratio = 1.50] and Tpeak3_gyroT [CV ratio = 1.17]) (Fig 19).

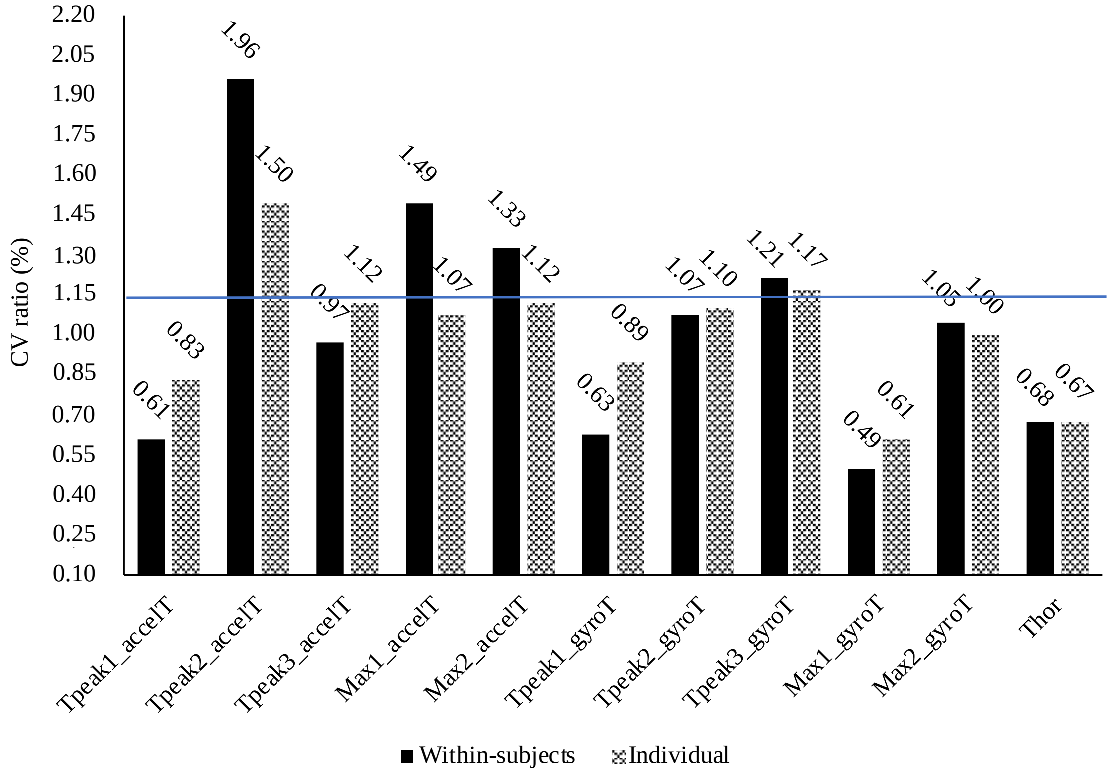


Figure 19. Reliability comparisons of the kinematic variables observed through the coefficient of variation (CV). The presented CV ratios are calculated as H1/N1. The smallest important ratio was considered to be 1.15.

3.1.3. *Ippon-seoi-nage* kinematic variables

Figure 20 shows the comparative analysis results of the *ippon-seoi-nage* kinematic variables between N1 and H1. The ascent to moderate altitude did not induce any relevant change in the time, acceleration or angular variables of the *ippon-seoi-nage*.

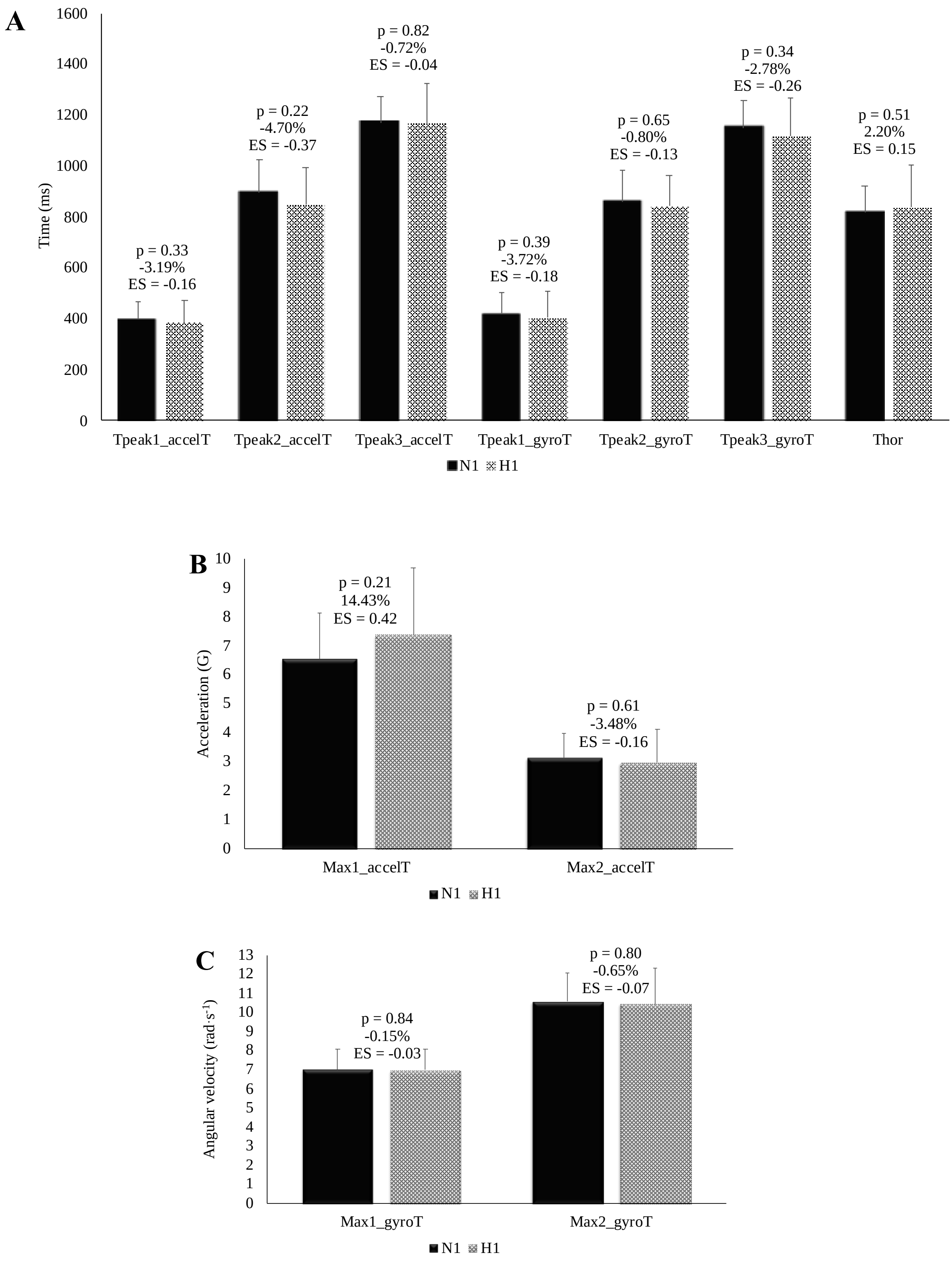


Figure 20. Acute effect of hypoxia on the time (A), acceleration (B) and angular variables (C) of the *ippon-seoi-nage*. Mean ± SD. Tpeak1_accelT, Tpeak2_accelT and Tpeak3_accelT, time to reach the first, second and third peak of the resultant acceleration, respectively; Tpeak1_gyroT, Tpeak2_gyroT and Tpeak3_gyroT, time to reach the first, second and third peak of the resultant angular velocity, respectively; Thor, time to reach the dummy's horizontal position; Max1_accelT and Max2_accelT, values of resultant acceleration that correspond to the peaks; Max1_gyroT and Max2_gyroT, values of resultant angular velocity that correspond to the peaks; N1: normoxia test; H1: hypoxia test; p: p-value; the magnitude of differences was expressed as standardized mean differences (Cohen's effect size, ES) and as percentage of change no significant differences between N1 and H1.

3.2. Effect of a power-oriented resistance training at moderate altitude

3.2.1. Leg extension mechanical variables

The CMJ training load assessed during the study is displayed in Figure 18. Similar moderate improvements in the CMJ training load were reached at the end of the training camp in both groups (mean difference ± SEM: 7.08 ± 1.67 kg, p = 0.002 vs. 6.67 ± 1.44 kg, p = 0.002 for HT and NT). No differences in the load linked to 1.2 $m \cdot s^{-1}$ of the MPV were found between groups in each week. However, a small but significant increase this load with respect to the pre-test load was observed in the HT from the first week (HT: 7.70%, p = 0.007; NT: 0.53%, p = 0.733), while the NT showed changes from the second week (Fig 21).

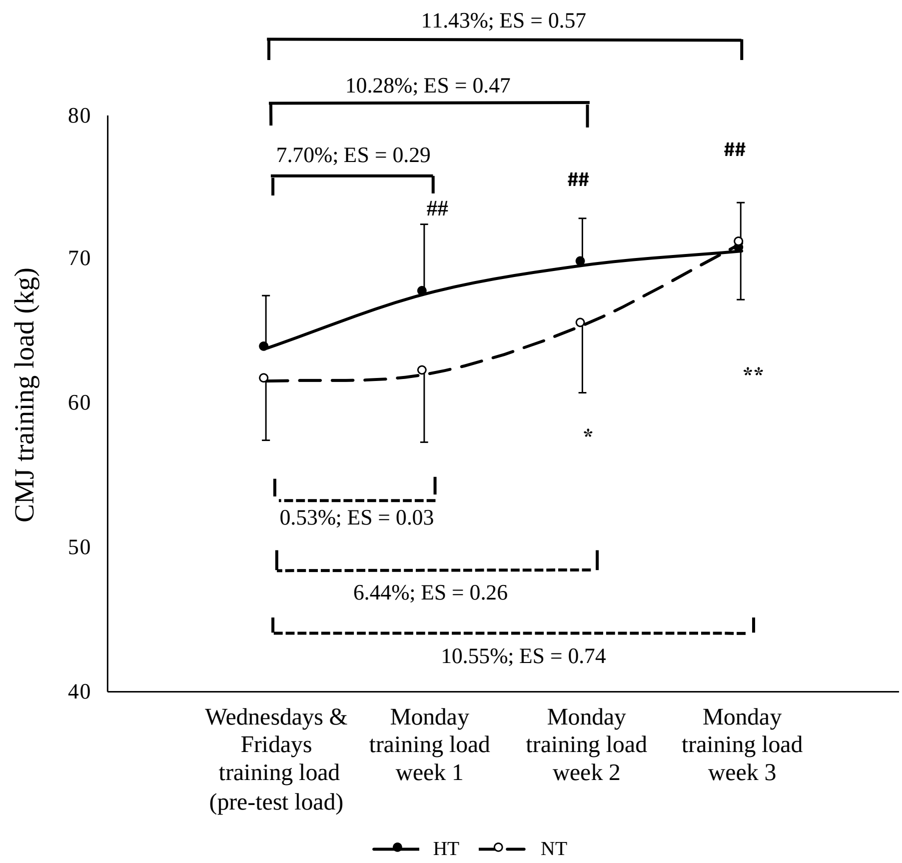


Figure 21. Training load linked to 1.2 m·s^{-1} of the mean propulsive velocity (MPV) throughout the training period. Wednesdays & Fridays' training load corresponded to the load associated to a MPV of 1.2 m·s^{-1} calculated in the pre-test in normoxia (N1); each Monday the training load was adjusted to a MPV of 1.2 m·s^{-1}, at the corresponding condition; HT: hypoxia training group; NT: normoxia training group; #, differences with respect to Wednesdays & Fridays' training load in HT; *, differences with respect to Wednesdays & Fridays' training load in NT; no significant differences between HT and NT at any time-point.

PV values corresponding to 25 to 100% BM are displayed in Figure 22. ANOVA showed a large main effect of time on PV at the 4 different loading conditions ($p < 0.001$, $\eta^2_p > 0.44$), mainly due to the increase of the PV in N2 and N3 with respect to N1. In N4, the effect of the training tends to decrease. A moderate to large time × altitude interaction effect ($p < 0.05$, $\eta^2_p > 0.16$) revealed that the highest PV was reached more quickly in the HT. Therefore, compared to pre-test (N1), HT displayed the best performance in PV in N2 (8.78 ± 1.32%, $p < 0.001$), while NT reached it in N3 (5.58 ± 0.72%, $p < 0.001$), showing a significant difference between these change percentages ($p = 0.03$). No main effect of altitude was observed on this variable at the 4 different loading conditions ($p > 0.05$, $\eta^2_p < 0.03$).

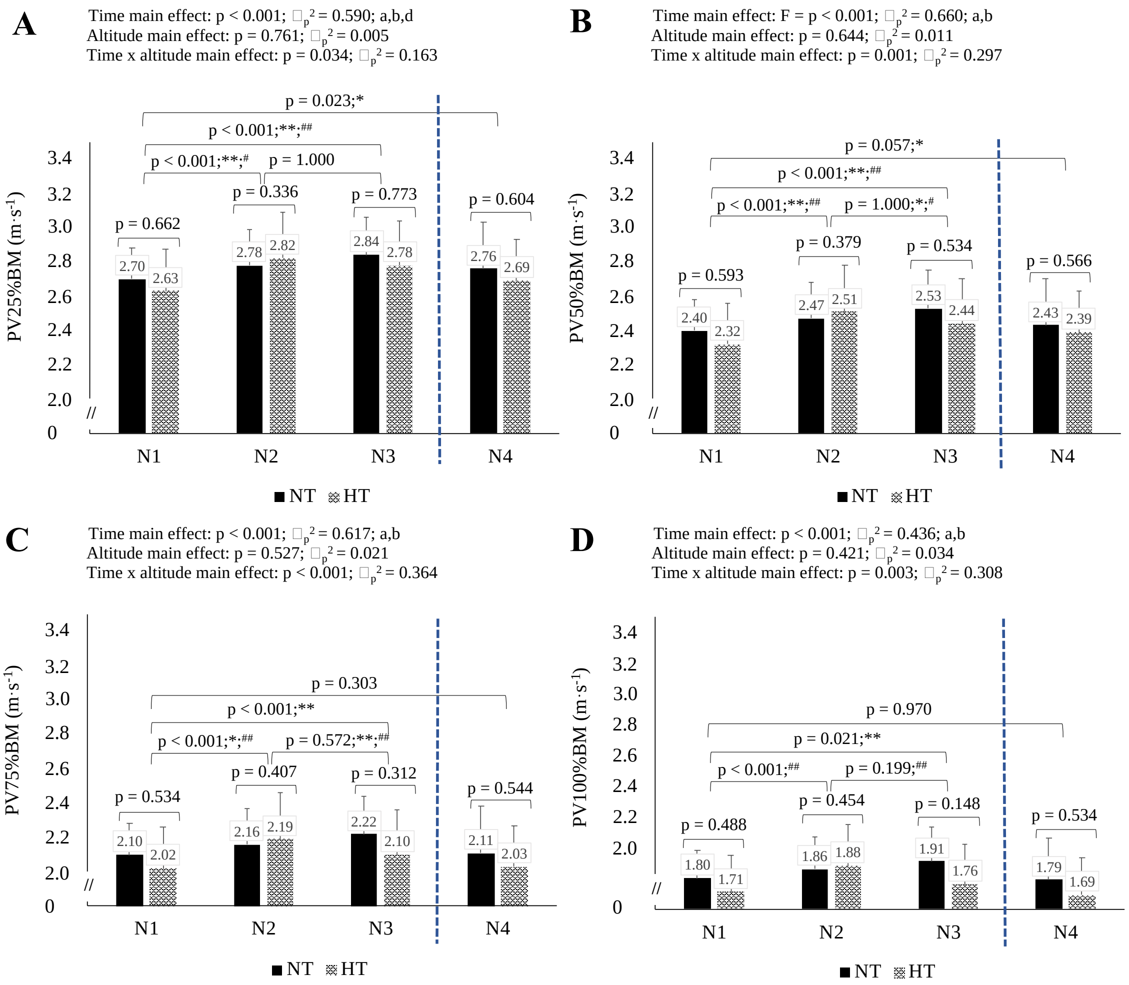


Figure 22. Peak velocities comparison through the study in both groups. PV25% BM, PV50%, BM PV75% BM, PV100% BM: peak velocity displacing an overload of 25, 50, 75 or 100% of the body mass. N1: pre-test; N2: post-test; N3: one week after training; N4: two weeks after training (not included in the general model). HT: hypoxia training group; NT: normoxia training group. p: p-value of the main effect in the general model; η^2_p: effect size through the partial eta squared value from the ANOVA test; a: N1 vs. N2 significant pairs from the general model; b: N1 vs. N3 significant pairs from the general model; c: N2 vs. N3 significant pairs from the general model; d: N1 vs. N4 significant pairs from the complementary mixed model N1 vs. N4; * pairs comparison between time periods in the NT (*** p < 0.001; ** p < 0.01; * p < 0.05); # pairs comparison between time periods in the HT (### p<0.001; ## p < 0.01; # p < 0.05); no significant differences between HT and NT at any time-point.

Regarding the load-velocity profile (determined using peak values of velocity), a significant main effect of time was observed on V_0 ($p < 0.001$, $\eta^2_p = 0.37$), due to the training effect on this variable from N2 in both groups. No time, altitude or time × altitude interaction effects were detected on L_0 nor on the S_{lv} ($p > 0.05$) (Table 7). Magnitude-based inferences are displayed in Figure 23.

Table 7. Altitude training effect on the maximal dynamic strength and the load-velocity profile.

	N1		N2		N3		N4	
	HT	NT	HT	NT	HT	NT	HT	NT
1RM ($kg \cdot kg^{-1}$)	1.85 ± 0.32	1.91 ± 0.22	1.83 ± 0.31	1.94 ± 0.17	1.75 ± 0.29	1.89 ± 0.13	1.70 ± 0.35	1.85 ± 0.22
V_0 ($m \cdot s^{-1}$)	2.94 ± 0.25	3.01 ± 0.20	3.19 ± 0.25 *	3.09 ± 0.23 *	3.12 ± 0.29 **	3.16 ± 0.24 **	3.03 ± 0.25	3.08 ± 0.28 *
L_0 (kg)	208.0 ± 31.34	187.2 ± 18.40	213.2 ± 20.96	191.78 ± 21.53	203.04 ± 37.85	191.31 ± 28.19	196.85 ± 25.64	194.06 ± 25.62
S_{lv} ($kg \cdot s \cdot m^{-1}$)	-71.67 ± 15.17	-62.43 ± 6.07	-67.42 ± 10.16	-62.15 ± 6.52	-66.35 ± 19.44	-60.84 ± 9.43	-65.32 ±1 0.58	-63.47±10.62

1RM: maximal 1 repetition relative to body mass. V_0: maximal theoretical velocity; L_0: maximal theoretical load; S_{lv}: load-velocity rela week after training; N4: two weeks after training (post-test control n = 9; not included in the general model); HT: hypoxia training group; N effect in the general model; η^2_p: effect size through the partial eta squared value from the ANOVA test; a: N1 vs. N2 significant pairs fro from the general model; c: N2 vs. N3 significant pairs from the general model; d: N1 vs. N4 significant pairs from the complementary mi was determined using peak values of velocity; * differences with respect N1 in HT and NT (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$); no time-poin

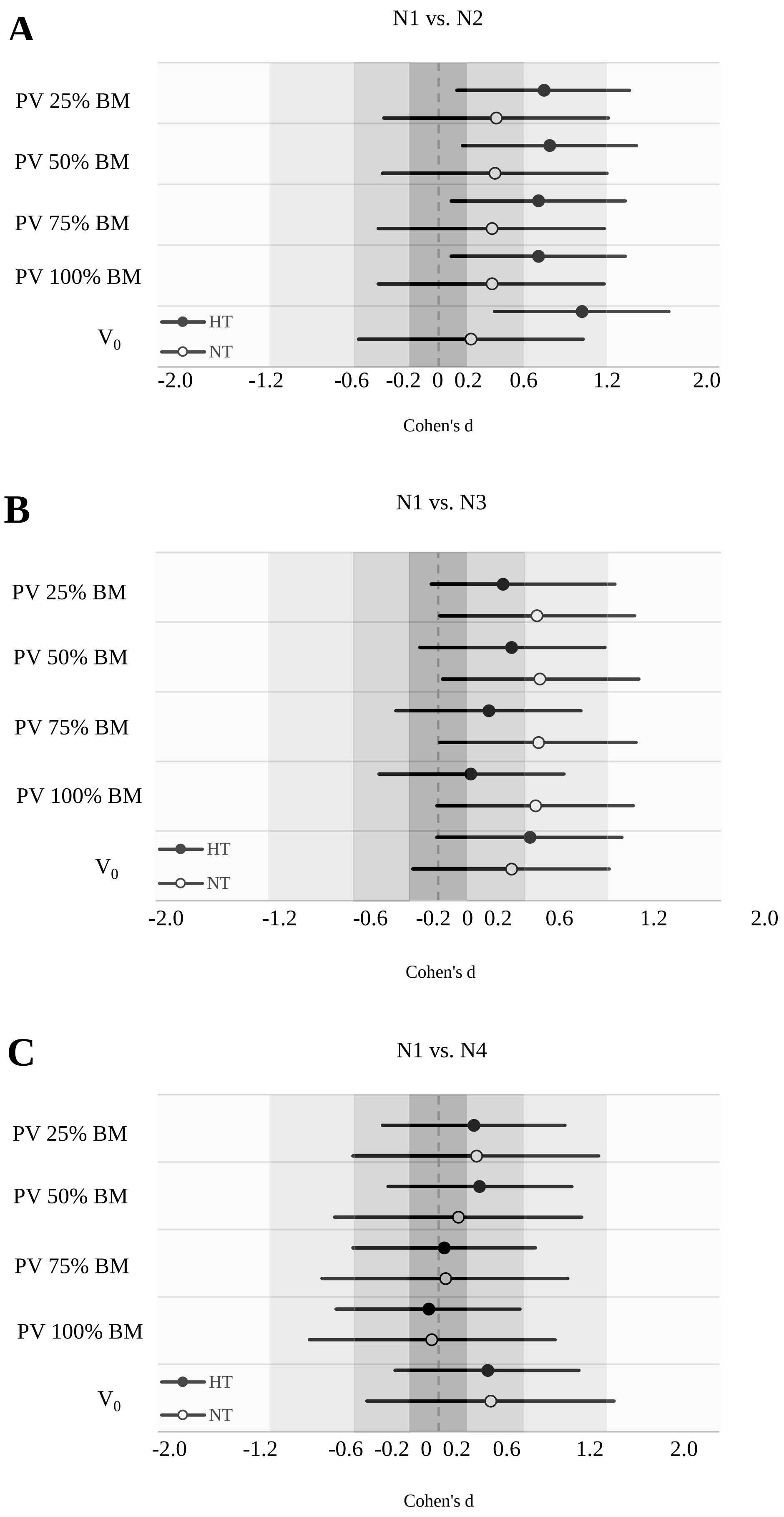

A
N1 vs. N2
PV 25% BM
PV 50% BM
PV 75% BM
PV 100% BM
V_0
HT
NT
-2.0 -1.2 -0.6 -0.2 0 0.2 0.6 1.2 2.0
Cohen's d
B
N1 vs. N3
PV 25% BM
PV 50% BM
PV 75% BM
PV 100% BM
V_0
HT
NT
-2.0 -1.2 -0.6 -0.2 0 0.2 0.6 1.2 2.0
Cohen's d
C
N1 vs. N4
PV 25% BM
PV 50% BM
PV 75% BM
PV 100% BM
V_0
HT
NT
-2.0 -1.2 -0.6 -0.2 0 0.2 0.6 1.2 2.0
Cohen's d

Figure 23. Cohen's d standardized mean differences with 95% confidence intervals for the peak velocities (PV) and for the maximal theoretical velocity (V_0) between N1 and N2 (A), N1 and N3 (B) and N1 and N4 (C). PV 25, 50, 75 and 100% BM: PV with 25, 50, 75 and 100% of the judoka's body mass; N1: pre-test; N2: post-test; N3: one week after training; N4: two weeks after training; V_0 was determined using peak values of velocity.

Regarding the force-velocity profile (determined using mean values of force and velocity), table 8 shows the main effect of time (N1, N2 and N3), altitude (HT vs. NT) and interaction time × altitude on current and optimal mechanical outputs of the F-V relationship and JH. Both groups displayed similar current (F_0, V_0, P_{max}) and optimal (OP-F_0, OP-V_0) mechanical outputs of the F-V relationship in pre-test (N1; $p > 0.05$). There was a main effect of the time on F_0 ($p = 0.005$, $\eta^2_p = 0.251$). Compared to pre-test (N1), HT displayed a moderate increase in F_0 in N2, while the difference in NT was small in N2 but moderate and delayed in N3 (11.76%, $p = 0.003$ for HT in N2 and 7.61%, $p = 0.014$ for NT in N3) (Fig 24). Changes in the S_{fv} between N1 and N2 in HT and between N1 and N3 in NT showed a practical significance (-18.28%, $p = 0.074$ and -13.41%, $p = 0.06$ for HT and NT, respectively). A small tendency to reduce the V_0 was observed in NT, reaching a practical significance one week after the training period (N3) (-5.44%; $p = 0.09$). There was a main effect of time on JH ($p = 0.02$, $\eta^2_p = 0.19$), mainly due to the increase achieved in N2 and N3. A moderate time × altitude interaction effect ($p = 0.03$, $\eta^2_p = 0.18$) revealed that the highest JH was reached more quickly in the HT. Therefore, compared to pre-test (N1), HT displayed the best performance in JH in N2 (8.20 ± 6.90%, $p = 0.001$), while NT reached it in N3 (1.41 ± 5.86%, $p = 0.504$), showing a significant difference between these change percentages ($p = 0.02$). No main effect of altitude was observed. Magnitude-based inferences are displayed in Figure 21.

Table 8. Altitude training effect on current and optimal mechanical outputs of the F-V relationship and jump height.

	N1		N2		N3		Time effect	
	HT	**NT**	**HT**	**NT**	**HT**	**NT**	**p**	**η^2_p**
F_0 ($N·kg^{-1}$)	29.98 ± 3.76	30.70 ± 2.74	33.34 ± 3.96**	32.17 ± 2.85¥	31.62 ± 3.37	32.95 ± 3.00*	**0.005**	**0.251**
V_0 ($m·s^{-1}$)	3.55 ± 0.50	3.80 ± 0.67	3.36 ± 0.70	3.53 ± 0.38	3.60 ± 1.04	3.53 ± 0.42¥	0.458	0.043
P_{max} ($W·kg^{-1}$)	26.30 ± 3.32	29.10 ± 5.03	27.74 ± 4.92	28.45 ± 4.05	28.20 ± 7.61	29.12 ± 4.63	0.537	0.034
S_{fv} ($N·s·m^{-1}·kg^{-1}$)	-8.75 ± 2.22	-8.32 ± 1.71	-10.35 ± 2.55¥	-9.18 ± 2.10	-9.38 ± 2.69	-9.44 ± 1.28¥	0.148	0.101
OP-F_0 ($N·kg^{-1}$)	38.46 ± 2.88	40.95 ± 3.57	39.49 ± 4.15	40.54 ± 3.11	39.68 ± 5.81	41.01 ± 3.40	0.579	0.030
OP-V_0 ($m·s^{-1}$)	2.73 ± 0.16	2.82 ± 0.27	2.79 ± 0.20	2.79 ± 0.21	2.81 ± 0.30	2.83 ± 0.24	0.554	0.032
OP-S_{fv} ($N·s·m^{-1}·kg^{-1}$)	-14.10 ± 0.53	-14.53 ± 0.66	-14.12 ± 0.57	-14.51 ± 0.66	-14.11 ± 0.69	-14.52 ± 0.65	0.966	<0.001
FV_{imb} (%)	61.85 ± 15.88	57.09 ± 10.57	73.81 ± 20.07¥	63.42 ± 8.96	66.91 ± 19.55	64.97 ± 7.81¥	0.125	0.109
JH (cm)	34.73 ± 5.18	38.01 ± 6.08	37.48 ± 5.82**	37.68 ± 5.55	37.13 ± 5.84*	38.71 ± 6.25	**0.017**	**0.192**

F_0: maximal theorical force relative to body mass; V_0: maximal theorical velocity; P_{max}: maximal theorical power relative to body F_0: optimal maximal theoretical force relative to body mass; OP-V_0: optimal maximal theoretical velocity; OP-S_{fv}: optimal slope optimal profile; N1: pre-test; N2: post-test; N3: one week after training; HT: hypoxia training group; NT: normoxia training group using mean values of force and velocity; differences with respect N1 in HT and NT (****** $p < 0.01$; ***** $p < 0.05$; **¥** $p < 0.10$); no signifi time-point.

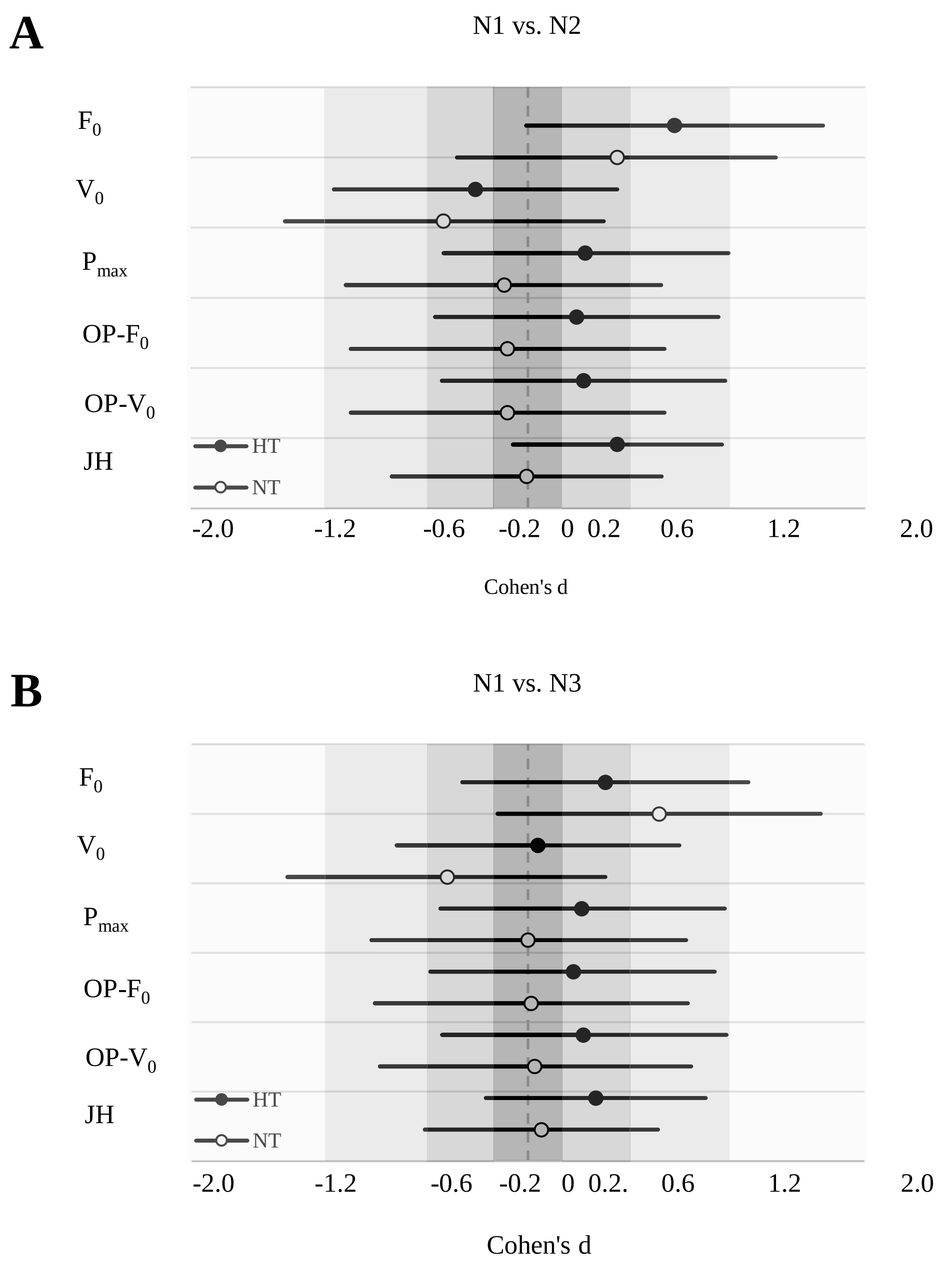


Figure 24. Cohen's d standardized mean differences with 95% confidence intervals for the force-velocity relationship variables between N1 and N2 (A) and N1 and N3 (B) in both groups. F_0: maximal theoretical force; V_0: maximal theoretical velocity; P_{max}: maximal theoretical power; OP-F_0: optimal maximal theoretical force; OP-V_0: optimal maximal theoretical velocity; JH: jump height. N1: pre-test; N2: post-test; N3: one week after training; HT: hypoxia training group; NT: normoxia training group; force-velocity relationship was determined using mean values of force and velocity.

Figure 25 displays both current and optimal F-V profiles from HT (A) and NT (B) in different time-points (N1, N2 and N3). Similar differences between current and optimal profiles were observed in each time-point (N1, N2 and N3) and altitude condition (HT and NT). P_{max} values did not change at any condition. The F-V profile displayed important imbalances due to lower current values in F_0 ($p < 0.001$, $\eta^2_p = 0.889$) and higher values in V_0 ($p < 0.001$, $\eta^2_p = 0.844$) compared with the optimal expected. A trend to a moderate reduction in the difference from the current to the optimal F-V profile was observed from N1 to N2 in HT and from N1 to N3 in NT (-11.96% and -7.88%, respectively; $p < 0.10$). No main effects of type × altitude or type × time or type × time × altitude were observed on any of the F-V profile variables.

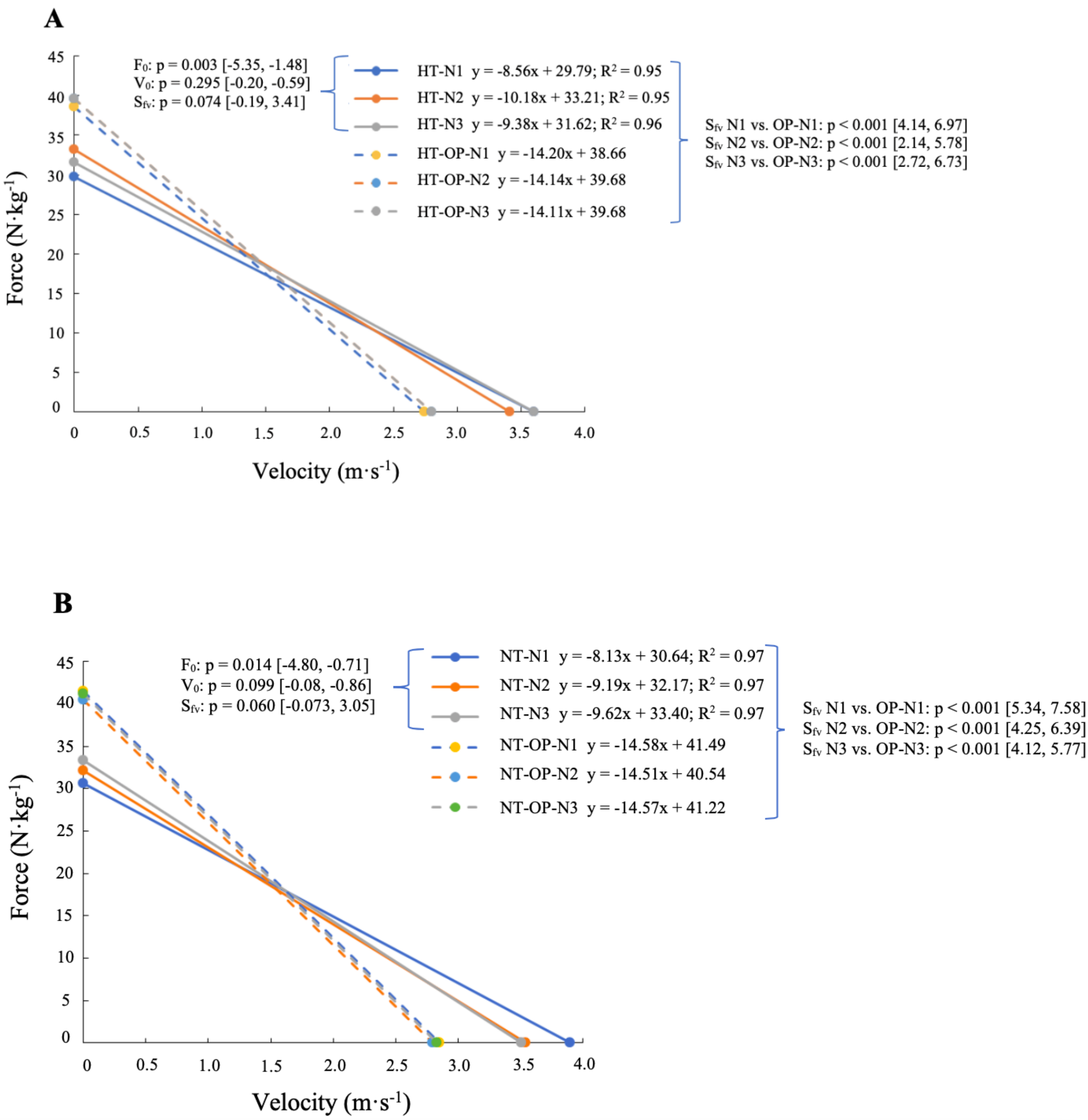


Figure 25. Current and optimal force-velocity profile before (N1), after (N2) and one week after (N3) the training period in HT (A) and NT (B). F_0: maximal theoretical force relative to body mass; V_0: maximal theoretical velocity; S_{fv}: slope relative to body mass; OP-S_{fv}: optimal slope relative to body mass; N1: pre-test; N2: post-test; N3: one week after training; HT: hypoxia training group; NT: normoxia training group; force-velocity relationship was determined using mean values of force and velocity.

3.2.2. *Ippon-seoi-nage* kinematic variables

A main effect of altitude was observed on times and maximal accelerations during the technical performance of the *ippon-seoi-nage* ($p < 0.05$; $\eta^2_p > 0.20$). HT had a smaller increase in the acceleration of the extension phase (Max2_accelT) than NT (difference between HT and NT of -22.95%, p = 0.03). Additionally, HT increased the time to reach the horizontal position (Thor) while NT decreased the time (difference between HT and NT of 18.68%; p = 0.003). No significant time or time × altitude interaction effects were observed (Table 9).

Table 9. Altitude training effect on *ippon-seoi-nage* kinematic variables.

	N1		**N2**		**N3**		**N4**	
	HT	**NT**	**HT**	**NT**	**HT**	**NT**	**HT**	**NT**
Tpeak1_ accelT (ms)	399.67 ± 72.44	353.3 ± 106.09	417.58 ± 69.77	344.22 ± 50.61 ¥	405.83 ± 108.37	330.33 ± 83.13	416.33 ± 93.35	327.25 ± 87.
Tpeak2_ accelT (ms)	899.83 ± 131.85	778.11 ± 131.08	960.75 ± 123.27	799.78 ± 74.26 ¥¥	909.42 ± 132.06	762.33 ± 131.73 ¥	940.22 ± 129.28	789.88 ± 11. ¥
Tpeak3_ accelT (ms)	1180.67 ± 101.55	1052.22 ± 127.52	1198.67 ± 89.01	1065.78 ± 87.41 ¥¥	1168.25 ± 117.42	1021.78 ± 93.40 ¥¥	1241.67 ± 116.42	1056.50 ± 123 ¥¥
Max1_ accelT (G)	6.35 ± 1.51	5.62 ± 1.23	5.70 ± 1.61	5.89 ± 1.47	6.39 ± 1.67	6.18 ± 1.67	5.85 ± 1.14	5.62 ± 1.4
Max2_ accelT (G)	3.08 ± 0.86	3.91 ± 0.98	3.03 ± 1.11	3.63 ± 1.40	2.78 ± 0.98	4.00 ± 0.98 ¥¥	2.48 ± 0.64	3.84 ± 0.8 ¥¥
Max3_ accelT (G)	30.5 ± 16.56	22.92 ± 8.53	31.84 ± 7.57	20.79 ± 5.66 ¥¥	33.09 ± 14.85	27.55 ± 9.37	34.71 ± 18.54	28.93 ± 13.
THor (ms)	817.17 ± 109.26	699.44 ± 113.03	912.17 ± 118.65 *	769.33 ± 104.81 ¥	861.00 ± 179.02	713.78 ± 103.61	932.89 ± 174.13	731.50 ± 95. ¥

Tpeak1_accelT: time from the beginning of the movement to peak 1 of resultant acceleration (AccelT); Tpeak2_accelT: time from the beginning of the movement to peak 2 of AccelT; Tpeak3_accelT: time from the beginning of the movement to peak 3 of AccelT; Max1_accelT: maximal acceleration reached in peak 1; Max2_accelT: maximal acceleration reached in peak 2; Max3_accelT: maximal acceleration reached in peak 3; Thor: time from the beginning of the movement to the horizontal position of the dummy; N1: pre-test; N2: post-test; N3: one week after training; N4: two weeks after training (post-test control n=9; not included in the general model); HT: hypoxia training group; NT: normoxia training group. p: p-value of the main effect in the general model; η^2_p: effect size through the eta squared value from the ANOVA test; a: N1 vs. N2 significant pairs from the general model; b: N1 vs. N3 significant pairs from the general model; c: N2 vs. N3 significant pairs from the general model; d: N1 vs. N4 significant pairs from the complementary mixed model N1 vs. N4; * differences with respect N1 in HT and NT (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$); ¥: HT vs. NT in the corresponding moment (¥¥¥ $p < 0.001$; ¥¥ $p < 0.01$; ¥ $p < 0.05$).

3.2.3. Body composition

No significant time (N1 vs. N3), altitude (HT vs. NT), or time × altitude interaction effects were observed on the anthropometrical (mass, mid-thigh circumference and fat percentage) and bioelectrical impedance analysis variables (total body water, body cellular mass, muscle mass and angle phase) ($p > 0.05$) (Table 10). ES analysis showed trivial non-significant differences between N1 and N3 in each group in all variables studied. There were no differences between the change percentages of HT and NT in any variable ($p > 0.05$).

Table 10. Altitude training effect on body composition variables.

	N1		N3		Time effect	
	HT	**NT**	**HT**	**NT**	**p**	**η^2_p**
Body mass (kg)	85.24 ± 23.95	80.78 ± 19.64	85.95 ± 22.60	80.89 ± 20.08	0.291	0.065
Mid-thigh circumference (cm)	55.14 ± 5.62	54.69 ± 4.67	55.35 ± 5.34	54.39 ± 4.86	0.791	0.004
% fat (Faulkner)	12.06 ± 4.18	11.64 ± 2.97	12.04 ± 4.01	11.64 ± 2.97	0.625	0.014
Total body water (l)	51.83 ± 10.46	49.80 ± 9.73	52.50 ± 9.36	49.34 ± 9.16	0.825	0.003
Total body water (%)	61.69 ± 3.99	62.13 ± 3.17	62.05 ± 4.50	61.63± 3.69	0.842	0.002
Muscle mass (kg)	50.84 ± 9.77	48.68 ± 9.30	51.54 ± 8.70	47.54 ± 7.72	0.698	0.009
Muscle mass (%)	60.69 ± 5.08	60.76 ± 3.28	61.00 ± 5.10	59.68 ± 5.06	0.421	0.039
Body cellular mass (kg)	41.95 ±8.05	40.14 ±7.65	42.52 ± 7.13	39.10 ±6.22	0.650	0.012
Phase angle (°)	7.29 ±0.71	7.17 ±0.42	7.25 ± 0.45	6.99 ± 0.48	0.329	0.056

N1: pre-test; N3: one week after training; HT: hypoxia training group; NT: normoxia training group; no significant differences between N1
between HT and NT in any time-point.

3.3. Correlation analysis between *ippon-seoi-nage* and leg extension capacity

Tables 11 and 12 show the correlation analysis between the kinematic variables of the *ippon-seoi-nage* and the leg extension mechanical variables at different time-points (N1, H1 and N2) for the HT and NT, respectively. No significant correlations were found between the *ippon-seoi-nage* kinematic variables (Max2_accelT and Max2_gyroT) and the leg extension mechanical variables (PV, 1RM, F_0, V_0 and P_{max}) in any group (HT or NT) or time-point (N1, H1 and N2). The Fisher's Z-transformed *r* coefficient comparison showed no differences between the correlations for HT in N1 vs. H1, nor N1 vs. N2 ($p > 0.05$) (Table 13). Similarly, no differences between the correlations for NT in N1 vs. N2 were found ($p > 0.05$) (Table 14).

Table 11. Correlation analysis between the *ippon-seoi-nage* kinematic variables and the leg extension mechanical variables at di
hypoxia training group (HT).

	Max2_accelT								
	N1		H1		N2		N1		
	r	**p**	***r***	**p**	***r***	**p**	***r***	**p**	***r***
PV ($m \cdot s^{-1}$)	-0.476 [-0.500; -0.439]	> 0.08	0.074 [0.042; 0.103]	> 0.737	-0.179 [-0.216; -0.137]	> 0.479	-0.525 [-0.540; -0.496]	> 0.057	0.159 [0.086; 0.
1RM ($kg \cdot kg^{-1}$)	-0.374	0.208	0.093	0.763	-0.059	0.847	-0.469	0.106	0.056
F_0 ($N \cdot kg^{-1}$)	0.447	0.125	-0.079	0.798	-0.255	0.400	-0.116	0.705	-0.07
V_0 ($m \cdot s^{-1}$)	0.039	0.899	0.331	0.269	-0.131	0.670	-0.019	0.952	0.358
P_{max} ($W \cdot kg^{-1}$)	-0.268	0.377	0.393	0.184	-0.316	0.293	-0.328	0.274	0.418

PV: peak velocity (mean of the correlations of the PV with 25, 50, 75 or 100% of the body mass and range); 1RM: maximal 1 repetiti
force relative to body mass; V_0: maximal theoretical velocity; P_{max}: maximal theoretical power relative to body mass; N1: pre-test in nor
normoxia; force-velocity relationship was determined using mean values of force and velocity; *r*: Pearson correlation coefficient; p:
variables in any time-point.

Table 12. Correlation analysis between the *ippon-seoi-nage* kinematic variables and the leg extension mechanical variables at differ
training group (NT).

	Max2_accelT				Max	
	N1		N2		N1	
	r	**p**	***r***	**p**	***r***	**p**
PV ($m·s^{-1}$)	-0.090 [-0.123; - 0.057]	> 0.719	0.163 [0.045; 0.286]	> 0.456	-0.265 [-0.298; 0.227]	> 0.374
1RM ($kg·kg^{-1}$)	-0.175	0.606	0.249	0.519	-0.284	0.398
F_0 ($N·kg^{-1}$)	-0.074	0.828	0.305	0.425	0.214	0.528
V_0 ($m·s^{-1}$)	0.240	0.476	0.361	0.340	0.292	0.383
P_{max} ($W·kg^{-1}$)	0.256	0.448	0.473	0.199	0.204	0.547

PV: peak velocity (mean of the correlations of the PV with 25, 50, 75 or 100% of the body mass and range); 1RM: maximal 1 re
theoretical force relative to body mass; V_0: maximal theoretical velocity; P_{max}: maximal theoretical power relative to body mass
normoxia; force-velocity relationship was determined using mean values of force and velocity; *r*: Pearson correlation coefficient; p:
any variables in any time-point.

Table 13. Comparison between the correlation analysis performed at different time-points (N1 vs. H1 and N1 vs. N2) in the hypox

	Max2_accelT					
	N1 vs. H1		N1 vs. N2		N1 vs. H1	
	z	**p [F > 2.60] = 0.05 [%95 CI]**	**z**	**p [F > 2.60] = 0.05 [%95 CI]**	**z**	**p [F > 2.6 [%95**
PV ($m \cdot s^{-1}$)	-1.871	ns [-1.211; 0.028]	-1.066	ns [-0.957; 0.283]	-2.353	ns [-1.364;
1RM ($kg \cdot kg^{-1}$)	-1.539	ns [-1.106; 0.133]	-1.057	ns [-0.954;0.286]	-1.786	ns [-1.185;
F_0 ($N \cdot kg^{-1}$)	1.772	ns [-0.059; 1.180]	2.348	ns [-0.123;1.363]	-0.135	ns [-0.662;
V_0 ($m \cdot s^{-1}$)	-0.963	ns [-0.924; 0.315]	0.541	ns [-0.449; 0.791]	-1.243	ns [-1-013;
P_{max} ($W \cdot kg^{-1}$)	-2.181	ns [-0.574; 0.666]	0.166	ns [-0.567; 0.672]	-2.483	ns [-0.313;

PV: peak velocity (mean of the correlations of the PV with 25, 50, 75 or 100% of the body mass and range); 1RM: maximal 1 re theoretical force relative to body mass; V_0: maximal theoretical velocity; P_{max}: maximal theoretical power relative to body mass; hypoxia; N2: post-test in normoxia; force-velocity relationship was determined using mean values of force and velocity; z: value o *r* coefficient comparison; F: value of Fisher's F distribution for $p < 0.05$; p: p-value; ns: non-significant difference; no significant di

Table 14. Comparison between the correlation analysis performed at different time-points (N1 vs. N2) in the normoxia training gro

	Max2_accelT		
	N1 vs. N2		
	z	**p [F > 3.18] = 0.05 [%95 CI]**	**z**
PV	-0.624	ns [-1.055; 0.546]	-1.004
1RM ($kg \cdot kg^{-1}$)	-1.057	ns [-1.232; 0.369]	-1.237
F_0 ($N \cdot kg^{-1}$)	-0.955	ns [-1.190; 0.4105]	-1.189
V_0 ($m \cdot s^{-1}$)	-0.325	ns [-0.933; 0.667]	-0.298
P_{max} ($W \cdot kg^{-1}$)	-0.618	ns [-1.052; 0.548]	-0.753

PV: peak velocity (mean of the correlations of the PV with 25, 50, 75 or 100% of the body mass); 1RM: maximal 1 repetition rel force relative to body mass; V_0: maximal theoretical velocity; P_{max}: maximal theoretical power relative to body mass; N1: pre-test in velocity relationship was determined using mean values of force and velocity; z: value of the statistic in the Fisher's Z-transformed *r* F distribution for $p < 0.05$; p: p-value; ns: non-significant difference; no significant differences between any correlations.

4 Discussion

4.1. Effect of acute exposure to moderate altitude

4.1.1. Leg extension mechanical variables

This study aimed to investigate the effect of an acute exposure to a moderate altitude on the leg extension mechanical variables. Acute hypoxia caused small increases in the PV of the CMJ loaded with 25 to 100% of the judoka's body mass, while no differences in V_0, L_0, S_{lv} (determined using peak values of velocity) and 1RM relative to body mass were observed (Fig 18 and Table 4).

As has been shown in previous studies, acute exposure to moderate altitude improves explosive actions in basic strength exercises (Chirosa et al., 2006; Feriche et al., 2014; García-Ramos et al., 2018) and in sports activities (Hamlin et al., 2015; Hollings et al., 2012; Levine et al., 2008). This may be related to various factors like reduction in aerodynamic resistance (Hahn & Gore, 2001; Hamlin et al., 2015; Levine et al., 2008), modified motor unit recruitment patterns due to an increased anaerobic metabolism (Balsom et al., 1994; Billaut et al., 2012) and a direct effect of hypoxemia on the supraspinal structures (Delliaux & Jammes, 2006; Feriche et al., 2017; Tomazin et al., 2020), which could justify the positive altitude effect on explosive exercise performance. Therefore, the ~4% improvement in leg extension PV observed in this study is in line with previous findings. Specifically, increases of ~3% in the loading condition associated with peak power output and ~6% in the 1RM in bench-press (Feriche et al., 2014), of ~7% in P_{max} and ~8% in V_0 in SJ and of 4% in peak power and JH in CMJ (García-Ramos et al., 2018).

4.1.2. Reliability of the *ippon-seoi-nage* kinematic variables

The analysis of the kinematic variables of the *ippon-seoi-nage* shows a great individual reliability of the technique in both conditions (N1 and H1), which contrasts with the low reliability observed when the whole group is considered. This result illustrates the difficulty in analyzing a complex sporting technique such as the *ippon-seoi-nage*, reflecting particular adaptations applied by each judoka.

Results displayed a great individual reliability of the time, acceleration and angular velocity variables both in normoxia and hypoxia, while a low reliability was observed when the whole group was considered (Tables 5 and 6). This result shows that *ippon-seoi-nage* individual performance patterns coexist and are highly reproduced by each judoka, while at the same time, they significantly differ from the technique used by others. Therefore, there is no general model of technical execution, since each judoka adapts the technique to his own characteristics. However, it would be necessary that *ippon-seoi-nage* teaching focused more on a suitable use of the legs, because judokas from this study seem to be performing the technique without applying a powerful leg extension, which is less effective from the technical point of view. The individual adaptation of the *ippon-seoi-nage* may be caused by different factors, such as morphology (Melo et al., 2013), physical condition or competitive level. The comparison between N1 and H1 has shown that after an acute ascent to a moderate altitude the reliability of the kinematic variables changed, and some variables became more reliable while others lost the reliability they previously showed in N1 (Fig 19). The increase in the CV ratio of the time needed to reach the peak 2 of the acceleration (Tpeak2_accelT) suggests a certain change in the space-time pattern of the *ippon-seoi-nage* and is evidence of the need to adjust and stabilize the technique after the ascent to moderate altitude.

The individual reliability results of this study confirm the utility of the use of a high sampling rate wearable sensor in the kinematic analysis of complex techniques in judo. Moreover, the reliability analysis allowed to determine which variables remained within the standard minimum references (CV < 15% and ICC > 0.70; Tables 5 and 6) and therefore displayed at least a good individual reliability to be considered as success criteria to improve *ippon-seoi-nage* performance. In this sense, the acceleration of the leg extension phase (Max2_accelT) and the time to reach the dummy horizontal position (Thor) were defined as the main success criteria for the *ippon-seoi-nage*.

4.1.3. *Ippon-seoi-nage* kinematic variables

This study aimed to assess if the acute exposure to a moderate altitude affected the times, accelerations and angular velocities transferred to the *uke* during the performance of the *ippon-seoi-nage* in elite judokas and its relationship with their leg extension capacity. Although acute hypoxia caused small increments in the leg extension PV, no changes in the kinematic variables of the *ippon-seoi-nage* were verified as a result of this.

Seoi-nage is one of the techniques most analyzed in judo, likely because it is the most commonly used in training and competition (Ishii, Ae, Suzuki, et al., 2018). However, the majority of the studies analyzing kinematic parameters of the technique focused on the performance of the *tori* (Blais et al., 2007; Ishii, Ae, Suzuki, et al., 2018; Melo et al., 2013), without examining the effect of that performance on the *uke*, which is the main goal of a throwing technique in judo. Therefore, according to Imamura (2006) the velocity and acceleration that *tori* is able to transmit to unbalance and throw *uke*, and not only *tori*'s capacity to move his own body at high speed before colliding with *uke*, is a parameter that should be considered for analysis. Nevertheless, only two studies considered the *uke*'s mechanical parameters (Imamura et al., 2006; Ishii & Michiyoshi, 2014), but they did not present data related with his resultant acceleration or angular velocity. Thus, to our knowledge, this is the first study to report direct acceleration and angular velocity measurements in the *ippon-seoi*-nage, which may provide a useful reference for future comparisons.

As previously stated, there are strong evidence that acute exposure to moderate altitude improves explosive actions (Feriche et al., 2014; García-Ramos et al., 2018; Hamlin et al., 2015). However the lack of improvement in the kinematic variables of the *ippon-seoi-nage* seems to contradict these findings, despite the explosive character of the movement and the great angular velocity (7.00 ± 1.07 rad·s^{-1} and 10.46 ± 1.85 rad·s^{-1} for Max1_gyroT and Max2_gyroT in H1) and acceleration (7.36 ± 2.32 m·s^{-2} and 2.97 ± 1.14 m·s^{-2} for Max1_accelt and Max2_accelt in H1) reached during the performance of *ippon-seoi-nage* (Fig 20). The duration of the *ippon-seoi-nage* (1.150 ± 0.108 s in N1; 1.117 ± 0.149 s in H1), determined as the time to reach the third peak of the angular velocity (Tpeak3_gyroT), is in accordance with the literature (Blais & Trilles, 2004).

4.2. Effect of a power-oriented resistance training at moderate altitude

4.2.1. Leg extension mechanical variables

The aim of this study was to analyze the influence of a moderate altitude power-oriented RT program on leg extension mechanical variables. Considering the load-velocity relationship, determined using peak values of velocity, the training period improved PV and V_0, both at moderate altitude and sea level. Considering the F-V relationship, determined using mean values of force and velocity, the training period improved F_0 and JH, regardless of the altitude condition. However, the F-V relationship in both groups at all time-points displayed low values of F_0, high values of V_0 and a general imbalance of the F-V profile when compared to the optimal predicted values. A time × altitude interaction effect was observed in PV and JH, indicating that the peak performance of each group was achieved at different time-points. Detailed analysis of this interaction showed that HT achieved a higher magnitude of change in leg push mechanical outputs and achieved it one week earlier (in N2) (Figures 22-25). These results suggest that a power-oriented RT in moderate altitude seems to accelerate and improve the gains in leg push capacity.

Previous RT studies conducted at natural altitude did not include a control group at sea level (García-Ramos et al., 2014; García-Ramos, Padial, et al., 2016), used other types of training such as concurrent training (García-Ramos, Stirn, et al., 2016), or applied power RT but under a LLTH strategy (Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, Argüelles-Cienfuegos, et al., 2018). A 3-week concurrent training at moderate altitude did not produce changes in the PV of the SJ of elite swimmers (García-Ramos, Stirn, et al., 2016). Two weeks of leg power RT at moderate altitude induced an improvement of 4.4% in PV (García-Ramos et al., 2014) and of 7.2% in height (García-Ramos, Padial, et al., 2016) of the SJ in elite swimmers. Similarly, our elite judokas achieved higher increases in PV and CMJ height after 3 weeks of power RT in HT than in NT (mean difference between conditions of 3.2% and 6.8% respectively). Four weeks of leg power-oriented RT at moderate altitude under a LLTH strategy induced a main effect of time on F_0 and P_{max}, as well as a main effect of training group on P_{max}, due to greater values displayed by the altitude group compared to the normoxia group (Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, Argüelles-Cienfuegos, et al., 2018).

Similarly to these results displayed by active university students, a main effect of time on F_0 was observed in the elite judokas from this study. Specifically, compared to the pre-test (N1), HT displayed a moderate increase in F_0 in N2 (11.76%), while NT improvements were smaller and delayed until N3 (7.61%) (Fig 24). Our findings support Morales-Artacho et al. (2018) conclusion that similar muscle strength responses can be achieved in both environmental conditions, contrary to earlier adverse associations between altitude and RT muscle adaptations.

Improvements in explosive actions at moderate altitude have been previously reported in different types of exercises (Feriche et al., 2014; García-Ramos et al., 2018). The reduction in air resistance with the ascent benefit performance of explosive actions (Hamlin et al., 2015; Hollings et al., 2012; Levine et al., 2008). In this study, although at lower magnitude (the PV reached during the actions evaluated was ~2-3 $m \cdot s^{-1}$), an altitude-induced benefit was observed on explosive leg capacity from the first exposure (Figures 21-25). The combined effect of the air density reduction and neuromuscular effects related to altitude ascent (Melissa et al., 1997; Schoenfeld, 2013; Scott, Slattery, Sculley, et al., 2014; Tomazin et al., 2020) potentially may explain the differences between these results and those achieved at normobaric simulated hypoxia (Feriche et al., 2014; Scott, Slattery, Sculley, & Dascombe, 2018; Scott, Slattery, Sculley, et al., 2015; Scott, Slattery, Sculley, Smith, et al., 2018)

There were no differences in RPE or global training load during the CMJ sets throughout the 3-week training period. There was no change in the 1RM, L_0 and S_{lv} after the training program or between groups. This result was expected since this mesocycle was designed to enhance explosive muscle performance (Cormie et al., 2011b) rather than maximal strength. Indeed, the power-oriented RT included a velocity-based training (Gonzalez-Badillo et al., 2017; Pareja-Blanco et al., 2014) and a contrast training (Alves et al., 2010; Cometti, 1998; Sale, 2002) in each session, both validated procedures to enhance muscle power. Both methodologies used complied with common power training guidelines on number of sets (3-6 sets), repetitions (3-6 rep/set) and inter-set rest periods (3-5 minutes) (Haff & Nimphius, 2012) (Fig 17). Notwithstanding, including a contrast training with moderate to high-load exercises (70-90% 1RM) allowed for maintenance of stable strength levels throughout the study period.

Using the CMJ pre-test load linked to 1.2 $m\cdot s^{-1}$ of the MPV allowed to orientate the RT program towards velocity enhancement on two of the three weekly training days. Indeed, large improvements in the PV of the CMJ were observed in both groups. Thus, mean PV increments of 8.78% for the HT and of 5.58% for the NT were observed from the pre-test. Moreover, having the training load readjusted to maintain the MPV of 1.2 $m\cdot s^{-1}$ at the corresponding condition every Monday induced a clear tendency to increase this load with respect to the pretest in HT from the first week (HT: 7.70%; NT: 0.53%), while the NT showed changes from the second week. This type of response has been observed in previous studies, highlighting the need to adjust the training load during resistance training at different altitude levels (> 1500 m) (Feriche et al., 2017; Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, Argüelles-Cienfuegos, et al., 2018; Rodríguez-Zamora et al., 2019).

Regarding the F-V profile (calculated using mean values), both groups displayed important imbalances due to lower current values in F_0 and higher values in V_0 compared to the optimal expected. Considering that judokas have to move high loads (opponent's body mass) in order to throw (Bonitch-Domínguez et al., 2010), this force deficit should be addressed as quickly as possible. In this sense, the power-oriented RT program applied in this study improved F_0 as mentioned before. Although no significant differences were found between the F-V imbalances of both groups at all time-points, complementary analysis showed a trend for a moderate reduction of the F-V imbalance from N1 to N2 in HT and from N1 to N3 in NT (-11.96% and -7.88%, respectively). This indicates a possible faster and stronger effect of altitude training on the reduction of the F-V imbalances.

The characteristics of the training program used in this study and the altitude effect likely explain why the lower-limb mechanical outputs increased in both groups and why the improvements in the HT were higher and achieved earlier than in NT, even though the differences between groups did not reach statistical significance. Batterham and Hopkins (2006) indicate that a non-significant result ($p > 0.05$) effect does not necessary imply that there is no worthwhile effect. In this sense, a review article on the hypoxic methods to achieve peak performance (Millet et al., 2010) reports that the smallest worthwhile effect on performance across a range of sports known for using altitude training (track and field, swimming, cycling) is ± 1%. It is possible that altitude training accelerates neuromuscular adaptations, due to a rise in the recruitment of type II fibers (Melissa et al., 1997; Schoenfeld, 2013; Scott, Slattery, Sculley, et al., 2014), an increase in spinal excitability (Amann et al., 2013; Delliaux & Jammes, 2006; Tomazin et al., 2016) or an enhancement in twitch contractile properties due to an upregulation of excitation-contracting coupling (Tomazin et al., 2020). Indeed, it is possible that judokas that trained at altitude reached their peak performance before N2, although it cannot be confirmed because there was not a mid-intervention assessment, which would have allowed to explore potential differences in the dynamics of training-induced responses. Similarly, Nishimura et al. (2010) found that RT under normobaric hypoxia improves muscle strength quicker than under normoxia (3 vs. 6 weeks).

According to Millet et al. (2010), a variability in aerobic performance is observed by coaches after a return to sea level. Aerobic peak performance is reportedly seen in some athletes from the 2nd to 4th day after returning to sea level, followed by a decrease up to the 15th-21st day (Chapman, Laymon Stickford, et al., 2014). Hamlin et al. (2018) meta-analysis reported that altitude training (real or simulated) appeared to be beneficial to improve high-intensity running performance in team-sport athletes, with enhanced performance over control groups persisting for at least four weeks post-intervention. Although there is a paucity of research on the post-altitude muscle power behavior, the best results in our study were reached the day participants returned to sea level (N2). Two weeks after the return to sea level (N4) the effect of the training in both groups tended to decrease (Fig 23).

4.2.2. *Ippon-seoi-nage* kinematic variables

The aim of this study was to analyze the influence of a moderate altitude power-oriented RT program on the technical performance of *ippon-seoi-nage* in elite judokas. The altitude training period induced an increase in time of execution and reduction in acceleration in the *ippon-seoi-nage* test, indicating a negative transfer of training. These results suggest that although a power-oriented RT at moderate altitude seems to accelerate and improve the gains in leg push capacity, the altitude itself and/or the derived physiological changes should be taken into account in program design for skill acquisition (i.e., technique training) during AT in sports with complex coordination movements.

Acute exposure to moderate altitude did not produce changes in the kinematic variables of the *ippon-seoi-nage*, although the analysis of the coefficient of variation ratio suggested a change in the space-time pattern of the technique (Almeida et al., 2018). In this study three weeks of an AT camp negatively affected the parameters of technical performance (Table 9). Thus, judokas showed a decrease in technical performance after AT, displaying a 22.95% smaller increase in the acceleration of the leg extension phase compared to NT, as well as an increase in the Thor vs. a decrease in NT (Δ18.68%). These results are contrary to what we expected, since other studies (García-Ramos, Padial, et al., 2016; García-Ramos, Stirn, et al., 2016) reported technique performance improvements in swimmers after altitude training. Disparities between findings are likely due to differences in the complexity of the movement, considering that the *ippon-seoi-nage* is a highly complex technique (Almeida et al., 2018; Ishii, Ae, Suzuki, et al., 2018). Accordingly, the swimming start can be classified as a simple technical maneuver, especially in elite swimmers, and thus the adaptations achieved from training at moderate altitude would conceivably have greater transfer to improved performance (García-Ramos et al., 2014; García-Ramos, Padial, et al., 2016; García-Ramos, Stirn, et al., 2016). Moreover, the swimmers spent 13.4% of their pool session time in specific starting technique training (García-Ramos, Padial, et al., 2016), whereas in this study judokas only spent 10.93% of the RT session time in specific technique training (18 to 24 *ippon-seoi-nage* throws 3 times per week). The design of the power oriented RT program applied was in accordance with Cometti (1998) recommendations on the use of exercises of different nature in addition to the loads used in contrast training, i.e., a specific contrast training with a moderate to high-load RT exercise and a judo specific exercise (*ippon-seoi-nage* throws) was included (Fig 17). Motor learning strategies are required to transfer improvements in strength to skilled performance (Suchomel et al., 2016). The length of time needed to achieve this transfer or lag time seems to be higher after altitude training. This is conceivably due to a higher change percentage observed in the PV of the CMJ in HT, requiring more time to accommodate higher changes, and also because altitude leads to changes in the space-time pattern of the technique that require time to adjust (Almeida et al., 2018). For this reason, transference work with specific technique exercises to allow the adjustments in its space-time pattern and to integrate the changes in physical performance into the technical performance should be included in the training program at this environmental condition.

This is the first study to investigate the altitude training effect on the technical performance of a highly complex non-cyclical sport movement. This could have applications in a variety of sports were complex skills assume great importance and which are considering altitude training for performance improvement at sea level.

4.2.3. Body composition

The effect of a moderate altitude power-oriented RT program on the body composition of elite judokas was one of the aims of this study. The training period did not induce significant changes in anthropometrical (mass, mid-thig circumference and fat percentage) and bioelectrical impedance analysis variables (total body water, body cellular mass, muscle mass and angle phase), nor the altitude condition affected these variables (Table 10). Magnitude of changes analysis (ES and change percentages) failed to find any significant change between time-points (N1 vs. N3) or altitude condition (HT vs. NT).

To be successful in judo high levels of strength and power are needed (Bonitch-Domínguez et al., 2010; Franchini, Del Vecchio, et al., 2011). Judokas try to maximize their muscle mass within the limits of their weight category in order to gain an advantage over weaker opponents (Artioli, Gualano, et al., 2010; Franchini et al., 2012). It has been reported that elite judokas have higher muscle mass, circumferences (flexed arm, forearm, wrist, medial calf) and breadths values (humerus and femur epicondyles) (Franchini, Takito, Kiss, et al., 2005; Kubo et al., 2006) than non-elite judokas. Thus, body composition seems to play a key role on competitive performance (Claessens et al., 1987; Sterkowicz-Przybycień & Franchini, 2013).

Prolonged exposure to altitude has been generally associated with losses in muscle mass and its functional capacity (Deldicque & Francaux, 2013; Perrey & Rupp, 2009). Reduced food intake linked to a loss of appetite (Calderón-Soto et al., 2011) and/or change in diet, increased energy expenditure due to a higher basal metabolic rate (Charlot et al., 2013), dehydration (Trujiens & Rodríguez, 2011) and absence of load adjustment during RT at altitude (Rodríguez-Zamora et al., 2019) are some of the factors likely responsible for this impairment. However, most of the studies were conducted at altitudes higher than the ones commonly used for sport training camps (> 5000 m vs. 2000-3000 m). Furthermore, the logistic aspects of high-altitude expeditions significantly differ from altitude training camp settings, where nutrition, sleep and training conditions are carefully controlled to maintain proper health conditions and consequently prevent muscle mass deterioration. Therefore, judokas from this study received strong recommendations to maintain their previous eating and sleeping habits and to pay especial attention to their hydration habits. Their training load was adjusted at altitude during the contrast training and in one of the three weekly sessions of the velocity-based training. This probably explains why no muscle losses or dehydration were reported after the training period.

These findings are of paramount importance for power sport coaches, since it has been demonstrated that a period of altitude training does not induce muscle loss, if proper sleeping, eating and training strategies are applied.

4.3. Correlation analysis between *ippon-seoi-nage* and leg extension capacity

The relationship between leg extension capacity and *ippon-seoi-nage* performance, as well as the altitude effect on the strength of this association has never been investigated. Although, the leg extension action has been considered a fundamental parameter in the technical performance of *ippon-seoi-nage* (Blais & Trilles, 2004; Ishii & Ae, 2015; Ishii, Ae, Koshida, et al., 2018), no significant relationship was found between the lower-limb extension capacity and the acceleration or angular velocity transferred to the *uke*. Acute exposure to hypoxia or training at different altitude conditions did not affect this association.

Judo techniques require high muscle power in lower-body muscle groups (Bonitch-Domínguez et al., 2010) and a judoka should be capable of applying this power, especially during the leg extension phase of the *ippon-seoi-nage* (represented in the movement sequence by the Peak2_accelT, Fig 14A). From a strictly technical point of view, *ippon-seoi-nage* gold standard execution highlights the leg extension action (Blais & Trilles, 2004; Ishii & Ae, 2015; Ishii, Ae, Koshida, et al., 2018). As a consequence, from a mechanical point of view, a rise in the PV during the CMJ should be linked to a rise in the acceleration and angular velocity in the peak 2 of the technique. However, this study failed to demonstrate this association between the kinematic variables of this judo technique (Max2_accelT and Max2_gyroT) and the leg push mechanical variables (PV, V_0 and normalized F_0, P_{max} and 1RM) in both groups (Tables 11 and 12). Although *ippon-seoi-nage* is a widespread technique, taught from early stages of judo training and consequently one of the techniques most used in training and competition (Ishii, Ae, Suzuki, et al., 2018), the absence of association could indicate that, at least in the sample studied, the leg implication during the *ippon-seoi-nage* was not sufficient according to the technical gold standard. Several reasons for this can be outlined such as having initially learned an incorrect technique pattern, lacking leg strength or substituting part of the leg action for actions of the arms, trunk or the turn itself. The fact that not all of the elite judokas in this study where specialists in this technique may also cause this lack of effective leg extension use. Moreover, as reported previously, judokas display reliable individual adaptations of the technique to their own characteristics, which can affect the studied association.

Future studies are needed to further investigate this possible association. Both acute exposure to hypoxia and training at different altitude conditions (normoxia or hypoxia) did not affect this association (Tables 13 and 14).

5 Conclusions
Conclusiones

The power-oriented RT program improved leg extension mechanical variables of elite judokas both at moderate altitude and sea level. A time × altitude interaction effect was observed in PV and JH, indicating that the peak performance of each group was achieved at different time-points. A detailed analysis of this interaction showed that training at moderate altitude induced greater and faster relative improvements. Moreover, *ippon-seoi-nage* performance was impaired after altitude training and no transference was verified between leg extension mechanical variables and technical performance. Specifically, this research concluded that:

1. Acute exposure to moderate altitude caused small increases in leg extension PV. This small change did not reach to affect maximal dynamic strength (1RM relative to body mass) or load-velocity relationship (L_0, V_0 and S_{lv}) determined using peak values of velocity.

2. High individual reliability of the *ippon-seoi-nage* kinematic variables contrasts with the low reliability when the whole group is considered. Therefore, there is no general model of technical execution, since each judoka adapts the technique to his own characteristics. The leg extension phase (Max2_accelT) and the time to reach the dummy horizontal position (Thor) were defined as the main success criteria for the *ippon-seoi-nage*. The effect of hypoxia on the reliability of the time variable linked to the leg extension in the *ippon-seoi-nage* (Tpeak2_accelT) could indicate changes in the space-time pattern of this technique.

3. The rise in the jump capacity observed after the ascent to moderate altitude is not followed by changes in time, acceleration and angular velocity of the *ippon-seoi-nage*, which indicates an absence of transference.

4. The power-oriented RT program improved leg extension PV and V_0 (determined using peak values of velocity) both at moderate altitude and sea level. The

time × altitude interaction effect in the PV, as well as the greater relative improvement in hypoxia suggest that altitude training may induce faster and higher improvements in the leg push capacity.

5. The power-oriented RT program did not induce any changes in the lower-limb maximal theoretical power (P_{max}) both at moderate altitude and sea level, while improvements in F_0 (determined using mean values of force and velocity) and JH were observed. Complementary results displayed a tendency to a faster and higher reduction of the F-V imbalance under hypoxic conditions.

6. Contrary to what was expected, altitude training increased the time of execution and reduced the acceleration in the *ippon-seoi-nage,* indicating a negative transfer from the leg power training. Although a power-oriented RT at moderate altitude seems to accelerate and improve the gains in leg push capacity, the *ippon-seoi-nage* impairment may be due to a paucity in specific technique-oriented training to allow transference from the improvements in physical capacity to technical performance and to integrate the changes caused by altitude exposure and training.

7. As expected, training at moderate altitude did not produce any changes in body composition. Judokas did not report losses in muscle mass or dehydration after the altitude training period, which is of paramount importance in power sports with weight categories such as judo.

8. No association was found between the leg extension capacity and the acceleration or angular velocity transferred to the *uke*, nor did acute exposure to hypoxia or training at different altitude conditions (normoxia and hypoxia) affect this association.

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El programa de entrenamiento orientado a la potencia muscular aumentó las variables mecánicas de extensión de piernas en judokas de élite, en altitud moderada y a nivel del mar. Se observó un efecto de interacción momento × altitud en la PV y JH, lo que indica que el pico de performance de cada grupo se alcanzó en momentos diferentes. El análisis pormenorizado de esta interacción demostró que entrenar en altitud moderada produjo mejorías relativas más acentuadas y rápidas. Además, se observó un empeoramiento en la ejecución del *ippon-seoi-nage* y no se verificó una transferencia entre las variables mecánicas de extensión de piernas y el rendimiento técnico. Específicamente, esta investigación concluyó que:

1. La exposición aguda a la altitud moderada causó pequeños incrementos en la PV de la extensión de piernas. Este pequeño cambio no llegó a afectar la fuerza dinámica máxima (1RM relativa al peso corporal) o la relación carga-velocidad (L_0, V_0 y S_{lv}) calculada a partir de valores pico de velocidad.

2. La alta fiabilidad individual de las variables del *ippon-seoi-nage* contrasta con la baja fiabilidad grupal encontrada. Esto indica que no existe un modelo general de ejecución técnica, ya que cada judoka adapta la técnica a sus propias características. La fase de extensión de piernas (Max2_accelT) y el tiempo hasta alcanzar la posición horizontal del *uke* (Thor) fueron considerados los principales criterios de éxito del *ippon-seoi-nage*. El efecto de la hipoxia en la fiabilidad de la variable temporal asociada a la extensión de piernas en el *ippon-seoi-nage* (Tpeak2_accelT) podría indicar cambios en el patrón espacio-temporal de l técnica.

3. El aumento en la capacidad de salto debido al ascenso súbito a altitud moderada no se acompaña por cambios en los tiempos, aceleraciones y velocidades angulares del *ippon-seoi-nage*, lo que indica una ausencia de transferencia.

4. El programa de entrenamiento orientado a la potencia muscular aumentó la PV y V_0 de la extensión de piernas en altitud moderada y a nivel del mar. El efecto de interacción momento × altitud en la PV, así como el mayor aumento relativo en hipoxia

sugieren que el entrenamiento en altitud puede mejorar la capacidad de empuje de las piernas, además de acelerar estas ganancias.

5. El programa de entrenamiento orientado a la potencia muscular no provocó cambios en la potencia máxima teórica (P_{max}) de las piernas en altitud moderada ni a nivel del mar, mientras se observaron incrementos de la F_0 (calculada a partir de valores medios de fuerza y velocidad) y JH. Resultados complementarios mostraron una tendencia a una mayor y más rápida reducción del desequilibrio del perfil F-V en hipoxia que en normoxia.

6. Contrariamente a lo esperado, el entrenamiento en altitud aumentó el tiempo de ejecución y disminuyó la aceleración del *ippon-seoi-nage*, lo que indica una transferencia negativa del entrenamiento de potencia de piernas. Aunque el programa de entrenamiento en altitud moderada parece acelerar y mejorar las ganancias en la capacidad de empuje de piernas, el empeoramiento del *ippon-seoi-nage* puede deberse a un insuficiente entrenamiento específico de la técnica. Es posible que un aumento del tiempo de entrenamiento específico de la técnica permita una adecuada transferencia de los incrementos en la capacidad física hacia la performance técnica, además de integrar los cambios causados por la exposición y entrenamiento en altitud.

7. Como se esperaba, el entrenamiento en altitud no provocó cambios en la composición corporal de los judokas. No se encontraron pérdidas de masa muscular ni deshidratación después de un periodo de entrenamiento en altitud, lo que es extremadamente importante en deportes de potencia con categorías de peso como el judo.

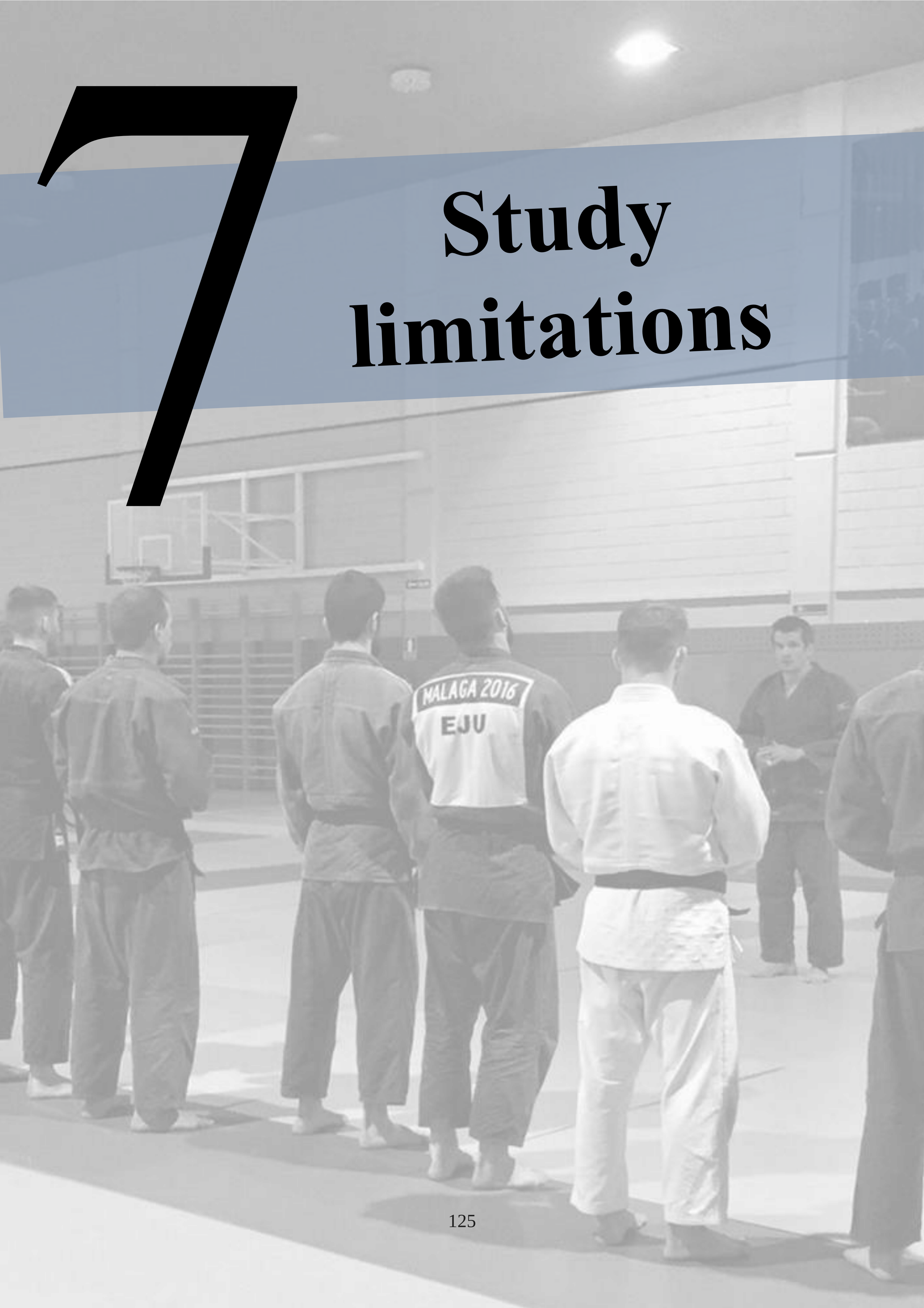
8. No se encontró una correlación entre la capacidad de extensión de piernas y la aceleración y velocidad angular transferida al *uke*. Esta asociación no se vio afectada por la exposición aguda ni por el entrenamiento en diferentes condiciones de altitud (normoxia o hipoxia).

6 Practical applications

A 3-week power-oriented RT program improved the leg extension mechanical variables of elite judokas both at moderate altitude and sea level. Training at moderate altitude seems to increase and accelerate the gains in these variables, which is consistent with previous research. Additionally, our results support the need to adjust the training load during altitude RT. The kinematic variables of the *ippon-seoi-nage* were negatively affected by the altitude training, increasing the times and reducing the accelerations transferred to the *uke* during the technique. To prevent this impairment, specific technique-oriented training should be included in altitude training programs. The same recommendations should be considered in sports with complex coordination movements, when designing altitude training periods.

The absence of association between the leg extension capacity and *ippon-seoi-nage* performance could indicate that, at least in the sample studied, the leg implication during the *ippon-seoi-nage* was not sufficient according to the technical gold standard. High individual reliability of the *ippon-seoi-nage* kinematic variables contrasts with the low reliability when the whole group is considered, due to individual adaptations of the technique. Thus, coaches should consider that *ippon-seoi-nage* individual performance patterns coexist and are highly reproduced by each judoka, while at the same time, they significantly differ from the technique used by others. However, it would be necessary that *ippon-seoi-nage* teaching focused more on a suitable use of the legs, because judokas from this study seem to be performing the technique without applying a powerful leg extension, which is less effective from the technical point of view. The effect of acute exposure to moderate altitude on the reliability of the time variable linked to the leg extension in the *ippon-seoi-nage* (Tpeak2_accelT) together with the changes in the jump capacity could confirm the need to adjust and stabilize the technique after the ascent to moderate altitude.

7 Study limitations

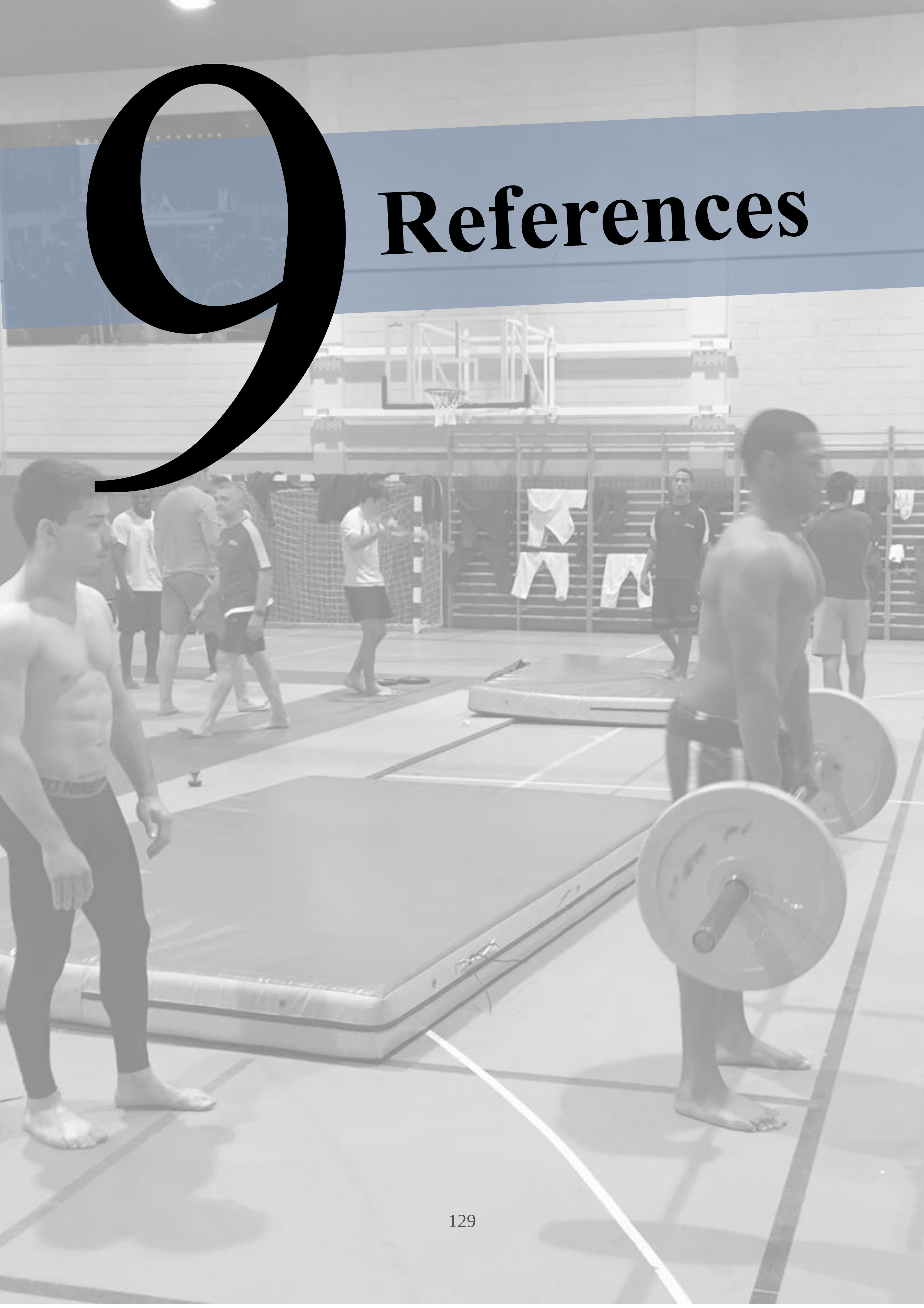


Limitations of this study can be addressed: 1) small sample size and great intragroup variability in technical and physical performance, since each group included elite judokas from -60 to +100 kg; 2) a possible placebo effect, which is a recurrent problem with terrestrial altitude studies, although it is important to note that judokas were not aware or given any information about the effects of altitude exposure on performance; 3) solely inclusion of data concerning the *uke*'s motion, consequently it was difficult to fully determine the relationship between the *tori*'s movements and the *uke*'s resultant movements; 4) although every participant mastered the *ippon-seoi-nage*, it might be that this specific technique was not always their favorite to apply in competition despite it is one of the most used; 5) finally, the present study did not comprise a mid-intervention assessment, which would have allowed to explore potential differences in the dynamics of training-induced responses.

8 Future research

Taken together, the findings of the present study warrant the need to further investigate the effect of a training program for leg extension capacity and its transference to the technique. Further research to clarify the principal mechanisms involved in muscle power training adaptations during and after an altitude training camp are also needed. Using a sample of elite judokas experts in the performance of *ippon-seoi-nage* would be useful to further investigate the possible association between the leg pushing capacity and *ippon-seoi-nage* performance. Studies including data from *tori*'s and *uke*'s motion would allow to have a deeper understanding of this relationship. Finally, considering that differences in physical and technical performance between judokas from the same competitive level and different weight category exist (Aruga et al., 2003; Franchini, Del Vecchio, et al., 2011; Sterkowicz-Przybycień & Franchini, 2013) a higher sample size that include only elite judokas of the same weight category would reduce the sample variability and allow to obtain more powerful results.

9 References



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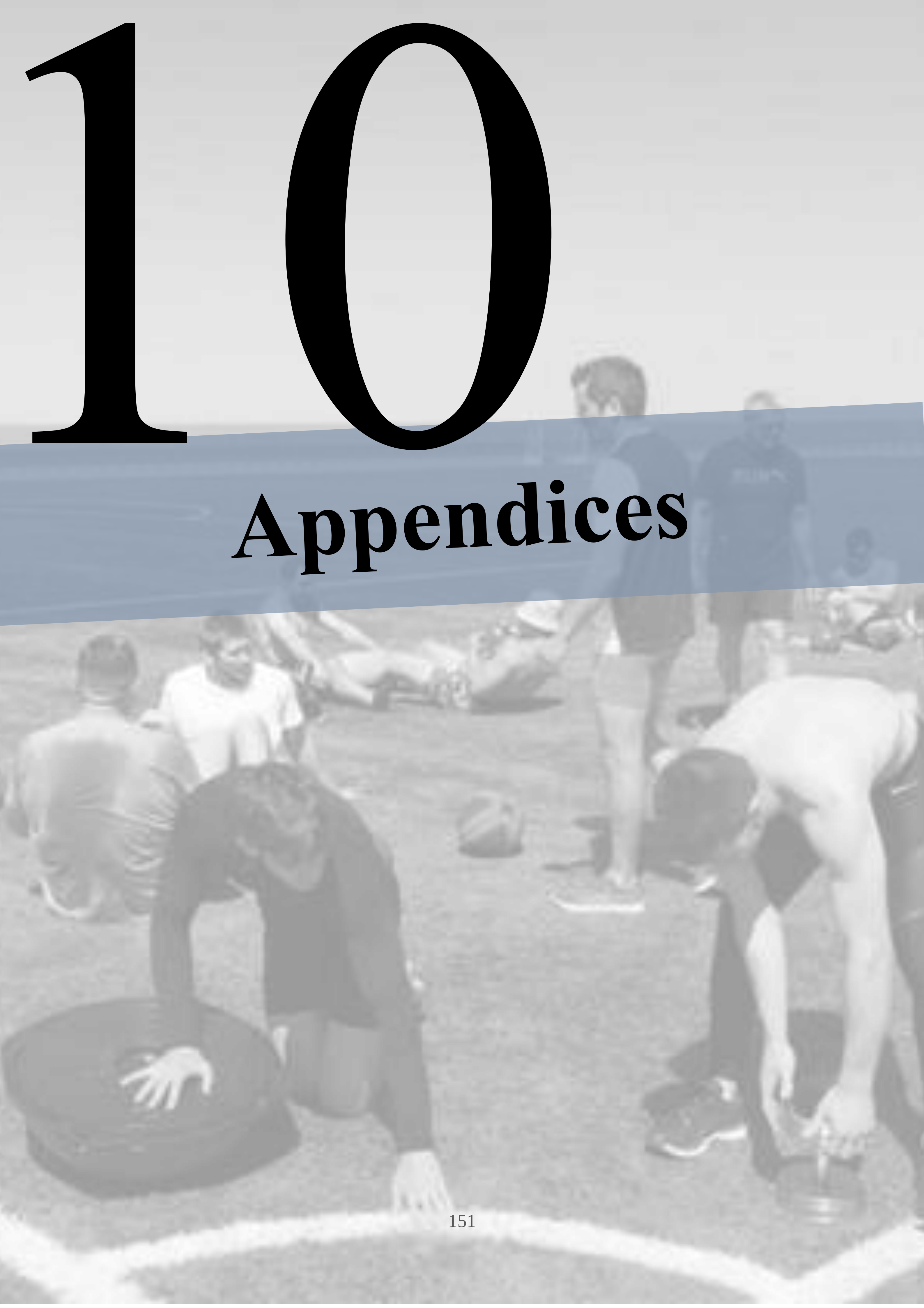

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Appendices

10.1. Appendix 1. Physical conditioning training program

Week 1	**May**
Adaptation of the first week of altitude training: decrease of the intensity and work density, by increasing the rest periods.	
Monday 22nd	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 4 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$, 4 min rest b) Contrast training (25 min) • 3 sets x (2 rep thruster 70% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Tuesday 23rd	**Warm-up:** 10 min jogging, joint mobility exercises **Coordination:** 15 min proprioceptive exercises **Large metabolic WOD:** a) 20 min AMRAP: • 30 push-up + 200 m run + 30 kettlebell swing (15-20 kg) + 200 m run **Core:** 5 sets EMOM 10 loaded sit-up (15-20 kg) **Cool-down:** 10 min jogging, dynamic and static stretching
Wednesday 24th	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 4 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$ determined in the pre-test, 4 min rest b) Contrast training (25 min) • 3 sets x (2 rep ½ squat 90% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Thursday 25th	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 5 min core, coordination work. **Medium metabolic WOD:** a) 4 sets x (40 s work + 20 s rest), 3 min rest: • rope jump • Burrell • jumping Jack • jumping pull-up with *judogi*'s grip

	Compensatory exercises: 3 sets x 10 rep lying led curl or Romanian deadlift 65% 1RM, 90 s rest **Core:** 5 sets EMOM 10 loaded back extension (15-20 kg) **Cool-down:** 10 min jogging, dynamic and static stretching
Friday 26th	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 6 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$ determined in the pre-test, 4 min rest b) Contrast training (25 min) • 3 sets x (2 rep sumo-deadlift-high-pull 70% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Saturday 27th	**Warm up:** 10 min jogging, joint mobility exercises **Activation:** 15 min plyometrics with the agility ladder (250 jumps) **Short metabolic WOD**: a) 3 sets x 10 rep (12 s *uchi-komi* + 8 s rest), 2 min rest **Compensatory exercises:** 3 sets x 10 rep lying led curl or Romanian deadlift 65% 1RM, 90 s rest **Core:** 5 sets x 1 min plank, 1 min rest **Cool-down:** 10 min jogging, dynamic and static stretching

Week 2	May - June
Monday 29th	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 6 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$, 4 min rest b) Contrast training (25 min) • 4 sets x (2 rep thruster 70% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Tuesday 30th	**Warm-up:** 10 min jogging, joint mobility exercises **Coordination:** 15 min proprioceptive exercises **Medium metabolic WOD:** • 4 sets x (20 s work + 10 s rest), 3 min rest: • rope jump • V abs • Burrell • superman • jumping Jack • mountain climber • jumping pull-up with *judogi*'s grip • fitball plank with hands on the floor and knee to chest **Cool-down:** 10 min jogging, dynamic and static stretching
Wednesday 31st	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 6 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$ determined in the pre-test, 4 min rest b) Contrast training (25 min) • 4 sets x (2 rep ½ squat 90% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Thursday 1st	**Warm up:** 10 min jogging, joint mobility exercises **Activation:** 5 min core exercises, coordination exercises **Short metabolic WOD**: a) 3 sets x 10 rep (20 s *uchi-komi* + 10 s rest), 5 min rest **Compensatory exercises:** 3 sets x 10 rep lying led curl or Romanian deadlift 65% 1RM, 90 s rest **Core:** 5 sets EMOM 10 loaded back extension (15-20 kg)

	Cool-down: 10 min jogging, dynamic and static stretching
Friday 2nd	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 6 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$ determined in the pre-test, 4 min rest b) Contrast training (25 min) • 4 sets x (2 rep sumo-deadlift-high-pull 70% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Saturday 3rd	**Warm-up:** 10 min jogging, joint mobility exercises **Coordination:** 15 min plyometrics with the agility ladder (250 jumps) **Large metabolic WOD:** a) AFAP (as fast as possible), maximum 20 min: • 20 burpees + 1 ball slam • 19 burpees + 2 ball slam • …until… • 2 burpees + 19 ball slam • 1 burpees + 20 ball slam **Core:** 5 sets x 1 min plank, 1 min rest **Cool-down** 10 min jogging, dynamic and static stretching

Week 3	June
Monday **5th**	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 4 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$, 4 min rest b) Contrast training (25 min) • 3 sets x (2 rep thruster 70% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Tuesday **6th**	**Warm-up:** 10 min jogging, joint mobility exercises **Coordination:** 15 min proprioceptive exercises **Large metabolic WOD:** a) 3 sets x 30 s work, 3 min active rest: • kettlebell swing • ring row • high-pull • push-up alternately changing the height of the hands • butterfly crunch • plyometrics with a hoop • 1-hand dumbbell snatch • 1-hand dumbbell snatch with the other hand • plank • burpee • overhead squat • 1-leg step-up **Cool-down:** 10 min jogging, dynamic and static stretching
Wednesday **7th**	**Warm-up:** 10 min jogging, joint mobility exercises **Activation:** 2 sets x 5 rep air squat, 3 sets x 5 rep CMJ (0, 10 and 20 kg) **WOD:** a) Loaded CMJ in Smith machine (25 min) • 6 sets x 6 rep with a load associated to 1.2 $m \cdot s^{-1}$ determined in the pre-test, 4 min rest b) Contrast training (25 min) • 4 sets x (2 rep ½ squat 90% 1RM + 6 *nage-komi*), 4 min rest **Cool-down:** 10 min jogging, dynamic and static stretching
Thursday **8th**	**Active rest**
Friday	**Testing session**

9th	
Saturday 10th	**Testing session**