The influence of physical activity levels on lactate production during squat training using a motorized resistance device (#99127)

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The influence of physical activity levels on lactate production during squat training using a motorized resistance device

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Objective: This study aimed to determine the association between changes in lactate production and levels of physical activity in a group of healthy young adults in response to two squat training protocols. **Material and methods:** Twenty-nine students majoring in Sports Science willingly participated in this study. Participants visited the lab four times within a two-week period, ensuring at least 48 h between visits. In each session, they completed three sets of 12 repetitions at 75% 1RM and three sets of 30 repetitions at 50% of maximum strength, with the order of protocols being randomized. **Results:** In the regression analysis, there was a significant positive association between lactate delta changes immediately post-squat at 50% of maximum strength at session 2 with the variable "sex: women" (β: 3.02, 95% CI: -0.18, 0.30, p=0.047) and BMI (kg/m²). Age exhibited a positive association (β: 0.19, 95% CI: 0.02, 0.36, p=0.032) with lactate delta changes immediately post-squat at 75% of maximum strength at session 2. There was also a significant inverse association between lactate delta changes at 10 min post-squat test exercise at 75% of maximum strength at session 1 and 2, and vigorous physical activity (-0.01, 95% CI: -0.02, 0.00, p=0.046). **Conclusion:** In summary, this study provides valuable insights into the association between lactate production and physical activity levels in young, healthy adults undergoing different squat training protocols. These findings suggest that intense physical activity may be associated with lower lactate production, indicating greater metabolic efficiency. In addition, sex differences in metabolic responses were observed, emphasizing the importance of personalized approaches in program design.

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Short tittle: Lactate production during squat training

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Abstract

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Introduction

In recent decades, strength training has garnered increasing interest across various domains (Brown, 2007; Hedrick, 1993; Zatsiorsky et al., 2020). This extends beyond enhancing physical capacity and athletic performance, encompassing improvements in body composition, overall health, as well as stress and anxiety reduction (Westcott, 2012). Focusing on a foundational element of strength training, the squat assumes particular significance. It finds application not only in fitness conditioning programs but also in rehabilitation and recovery regimens for diverse injuries (Comfort & Kasim, 2007). Moreover, the squat isn't confined to gymnasiums and training facilities (Schlegel & Fialová, 2021); it's a movement pattern replicated in everyday activities such as rising from and sitting in a chair, ascending, and descending stairs, picking objects from the ground, and more (Lo et al., 2022). Therefore, understanding the physiological aspects of strength training, specifically pertaining to the squat exercise, could hold pivotal importance in optimizing strength training (Hettinger, 2017).

Transitioning into the physiological realm, lactate is a metabolic marker intricately tied to physical exercise, which has been subject to meticulous scrutiny in the realm of endurance for many years (A. M. Jones & Carter, 2000). In fact, numerous articles assert that the exercise intensity corresponding to the increase in blood lactate above resting levels are potent predictors of performance in endurance training (Beneke et al., 2011). On the other hand, the lactate threshold marks the point at which blood lactate concentrations begin to increase exponentially from resting values (Davis, 1985). As for the study of this variable during strength training, it has been

examined to a lesser extent and not for as long, but there is indeed literature indicating its behavior (Dominguez et al., 2018; Garnacho-Castaño et al., 2015).

In connection with this, it becomes especially relevant to understand how lactate production varies at different intensities of strength training, with particular attention to the variation in prescription of repetitions and load percentage in the squat (Garnacho-Castaño et al., 2015). This study will generate new insights and shed light not only on lactate production following the completion of two protocols with different squat training intensities but also on the relationship between lactate production and levels of physical activity in a group of young, healthy adults. This will provide a deeper understanding of the effects of different training protocols on the body's metabolic response.

Furthermore, assessing lactate levels during strength training and recovery is important because it provides valuable information about the metabolic response to exercise and the effectiveness of training sessions (Garnacho-Castaño et al., 2015). Lactate production is closely correlated with energy metabolism and can be used as a biomarker for fat oxidation in skeletal muscles (Lee et al., 2023). Monitoring lactate levels during training sessions can help coaches and athletes understand the level of adenosine triphosphate breakdown and the energy system contribution involved in muscle energy coverage during intense sprints (Kantanista et al., 2021). Additionally, lactate measurements can be used to estimate the maximal lactate steady state intensity, which represents the balance between lactate appearance and clearance in the bloodstream (Messias et al., 2017). Furthermore, lactate clearance during recovery periods can be indicative of the body's ability to recover and adapt to the training stimulus (Lopes et al., 2014). Overall, assessing lactate levels during strength training and recovery provides insights into energy metabolism, training effectiveness, and recovery capacity.

The uniqueness and relevance of this study lies in its ability to provide specific and applicable guidelines, supported by rigorous data and comprehensive analyses regarding the metabolic response to muscular strength training. Thus, the aim of this study was to determine the association between changes in lactate production and levels of physical activity in response to two squat training protocols (30 repetitions at 50% 1 repetition maximum (RM) and 12 repetitions at 75% 1RM) in a group of healthy young adults.

Materials & Methods

Subjects

Twenty-nine healthy subjects (age: 24.9 ± 4.6 years; height: 1.70 ± 0.1 m; body mass: 68.1 ± 12.9 kg; BMI: 23.5 ± 3.0 kg/m^2), including thirteen males and sixteen females, willingly participated in this study (Table 1). All participants met the eligibility criteria, which entailed (a) having no medical conditions and (b) having at least one year of experience in muscle strength training.
In the initial assessment to confirm eligibility, female participants were inquired about their menstrual cycle. This involved details like the start and end dates of their most recent menstruation, length of their menstrual cycle, any instances of intense discomfort or excessive bleeding, and use of hormonal contraceptives. We specifically assessed them during the luteal phase (Bisdee et al., 1989). Additionally, none of them relied on hormonal contraceptives, and only two reported experiencing severe pain and heavy bleeding. The study protocol was approved by the Committee

on Human Research of the University of Granada (no. 2182/CEIH/2021) and was conducted in accordance with the Declaration of Helsinki.

Intervention

A repeated measures design was employed to assess variations in EE during two different acute with or w/out arm swing squat exercise protocols using functional electromechanical dynamometry (FEMD). Following one session of familiarization and 1RM determination, participants visited the lab four times within a two-week period, ensuring at least 48 hours between visits. In each session, they completed 3 sets of 12 repetitions at 75% 1RM and 3 sets of 30 repetitions at 50% 1RM, with the order of protocols being randomized.

Data collection procedures

During the study, participants underwent a total of five sessions, including one familiarization session and four experimental sessions. They were instructed to ensure a minimum of 8 hours of sleep and to avoid smoking, engaging in vigorous exercise within 12 hours before testing, and eating at least one hour prior to the session. Participants arrived at the laboratory at the same time each day (within a one-hour window) and were exposed to similar environmental conditions, with a temperature of approximately 22°C and humidity of 60%.

Participants followed the researcher's instructions upon arrival. When they arrived at the laboratory, as it was done in del-Cuerpo (del-Cuerpo et al., 2023; Del-Cuerpo et al., 2023), they wore a gas analyzer mask and sat in a relaxed position for five minutes for initial gas analysis. At this time, capillary blood samples were collected from a finger and then analyzed. They then put on a vest equipped with a carabiner connected to an FEMD cable. After a 5-minute warm-up on a cycle ergometer, they did repetitions at 10% of their 1RM. After a 5-minute rest, they performed three sets of 12 repetitions at 75% 1RM or 30 repetitions at 50% 1RM. Post-exercise gas analysis was conducted while seated for ten minutes. The exercise order was randomized with 5-minute breaks between sets. EE was determined indirectly using a metabolic cart, which analyzed respiratory gases. Immediately after the completion of the session, as well as 10 minutes post-exercise, another capillary blood sample was taken from the participants' finger and analyzed Prior studies have confirmed the test-retest reliability of the FEMD for squat training (del-Cuerpo et al., 2023). The study protocol is outlined in Figure 1.

[Figure 1 near here. Protocol measurement of the squat exercise]

During their initial lab visit, participants engaged in a 60-minute session. This session aimed to familiarize them with the FEMD and establish their 1RM. This consisted of (a) a general warm-up comprising 2 sets of 10 squat repetitions, starting with a load of 10 kg and increasing by 2 kg per repetition. There was a 40-second rest between sets. Additionally, (b) the participants' squat 1RM was directly estimated. This began with a load equivalent to 100% of the male participants' body weight and 80% for the female participants. The load increased in 4 kg increments up to 10 repetitions. The protocol used to determine the partcipants' 1RM is the one used in del-Cuerpo (2023) (del-Cuerpo et al., 2023; Del-Cuerpo et al., 2023).

Measurements

To ensure uniform nutritional conditions among participants and minimize external influences on the results, all participants' diets were adjusted a week before and throughout the study. This involved the exclusion of potential influencing factors like caffeine and supplements. A qualified Human Nutrition and Dietetics graduate tailored a weekly diet to each participant's energy requirements during this period. These requirements were determined through anthropometric measurements taken a week before the study and in subsequent weeks. These measurements encompassed weight (measured with a professional TANITA SC-240-MA scale with a biological suite), height (measured with a portable Seca 213 Stadiometer), and skinfold measurements for various areas, along with arm and mid-thigh circumferences, all taken by an ISAK level 1 anthropometrist using respective tools. Basal EE was computed using the Harris-Benedict formula (Chmielewska et al., 2023), total EE was determined using the appropriate activity factor, and body fat percentage was estimated using the Foulkner formula (L. M. Jones et al., 2020).

with or w/out arm swing???

The half squat exercise was conducted using the FEMD (Dynasystem, Model Research, Granada, Spain), a validated isokinetic multi-joint device capable of assessing various strength parameters such as speed, power, work, and impulse in one instrument (del-Cuerpo et al., 2023; Rodriguez-Perea et al., 2021). Each participant's physical activity level (PAL) was evaluated using the International Physical Activity Questionnaire (IPAQ) short form, a reliable tool for assessing physical activity in adults aged 18 to 69 years (Roman-Viñas et al., 2010).
In order to measure lactate production, blood samples were collected from the index finger of each participant using sterile single-use safety lancets (Accu-Chek Safe-T-Pro Plus, Deutschland). Prior to collection, the site was cleaned to remove any sweat or blood and then lanced with a sterile single-use lancet. Test strips inserted into a reliable and valid device: Lactate Pro 2 (Arkray, Kyota, Japan) (Crotty et al., 2021) were then sequentially placed against the surface of this blood sample until beeps were audible, signifying the start of analysis. The same operator collected and analyzed all blood samples throughout the study.

For measuring energy expenditure (EE) during both protocols, the FitMate™ metabolic system (Cosmed, Rome, Italy) was employed. This is a dependable and validated metabolic analyzer designed to measure oxygen consumption and EE during both rest and exercise, analyzing breath-by-breath ventilation as well as expired oxygen and carbon dioxide levels (Chmielewska et al., 2023). The device self-calibrates before testing each subject and does not require a warm-up period. The mask was worn by the participant for ten minutes after completing the exercise. In case of poor fit, the device alerted with a warning on the screen. The utilization of this device did not interfere with the execution of the squat protocol in any way.

Statistical analyses

Statistical analysis was performed using SPSS® v23.0 software. Data are presented as the mean and standard deviation (SD). Normality and homoscedasticity assumptions for all data were checked using the Shapiro–Wilk and Levene tests. Differences between groups according to PAL were determined using the Student t-test. Delta changes were determined by comparing Pre vs ImmPost test and after 10 minutes post-test. To investigate the association of lactate delta changes with sex, age, BMI, and PAL, a multivariable regression was conducted with results reported as

beta coefficient (b) and their 95% CI. The sample size for this experimental study was determined using statistical software (G*Power version 3.0.10), based on a test power of 90% and a statistical significance level of 5%, with an effect size of 0.8.

Results

Descriptive characteristic of the subjects participating in this study depending on their PAL is shown in table 1.

[Table 1 near here. Descriptive characteristics of the sample based on PAL]

In the comparison based on PAL (Table 2), the High-PAL reported lower delta change in Pre vs ImmPost test at 75% 1RM session 1 (S1) (Low-PAL 5.66±2.86 vs. High-PAL 3.69 ±2.31, P=0.050) and delta $Post_{10min}$ at 50% 1RM S1 (Low-PAL 6.52±3.28 vs. 4.11±2.26, P= 0.030).

[Table 2 near here. Delta change immediately and 10 minutes post-squat exercise.]

In the regression analysis, there was a significant positive association between lactate delta changes immediately post-squat at 50% 1RM session 2 (S2) with the variable "sex (biological attributes that are associated with physical and physiological features): women" (β: 3.02, 95% CI: -0.18, 0.30, p=0.047) and BMI (kg/m²). Age exhibited a positive association (β: 0.19, 95% CI: 0.02, 0.36, p=0.032) with lactate delta changes immediately post-squat at 75% 1RM S2 (table 3).

[Table 3 near here. Association of lactate delta changes immediately post-squat test with PAL]

In the regression model, there was a significantly inverse association between lactate delta changes 10 minutes post-squat test exercise at 75% 1RM S1 and S2 and vigorous physical activity (-0.01, 95% CI: -0.02, 0.00, p=0.046) (table 4).

[Table 4 near here. Association of lactate delta changes 10 minutes post-squat test with PAL]

Discussion

The main purpose of this study was to determine the association between changes in lactate production and levels of physical activity in response to two squat training protocols (30 repetitions at 50% 1RM and 12 repetitions at 75% 1RM) in a group of healthy young adults. The obtained results indicate that (1) subjects with higher PAL report lower lactate production during squat

exercises at 50% and 75% 1RM, (2) women exhibit an association with higher lactate production than men in squat exercises, and (3) higher age is correlated with greater lactate production.

Before delving into the obtained results, conducting an in-depth literature review, we observed that most articles discussing blood lactate concentration or lactate clearance and its behavior in trained or sedentary subjects date from the 1970s to around 2010. There are few articles investigating this aspect today. Furthermore, while lactate production during training has been more extensively investigated in endurance training to the best of our knowledge, there are also some studies, albeit to a lesser extent, that examine it during strength training. It would be interesting to have more current articles that evaluate this variable in subjects with different PAL. However, we believe that this is precisely what gives uniqueness to our research.

As a primary finding of this study, we observed a strong association between self-reported PAL and lactate production during squat exercise. Our results align with those published by Hu et al. (2009) (Hu et al., 2009), who sought to assess the effects of strength training on work capacity and parasympathetic heart rate modulation during exercise in physically inactive men. For this purpose, they compared a sedentary control group with an experimental group that underwent 10 weeks of progressive strength training. A decrease in blood lactate levels at submaximal intensities was observed compared to the control group. This is due to adaptations involving greater lactate removal and oxidation in active muscles (L. A. Messonnier et al., 2013). It has been shown that training alters the activity of lactate dehydrogenase by shifting its distribution toward a higher proportion of its H-LDH isoenzyme (L. Messonnier et al., 2001), which is more favorable for lactate oxidation to pyruvate than the M-LDH isoenzyme. Training has also been shown to increase muscle oxidative capacity and lactate oxidation through enhancements in mitochondrial mass and the expression of mitochondrial constituent proteins (Hood et al., 2011; Pesta et al., 2011).

Regarding to sex association to lactate production, despite observing that in three out of four sessions there is no association between sex and lactate production, men still exhibit higher lactate levels. Conversely, we do find a significant and positive association between lactate production and female in the second session at 50% of 1RM, but this is not the case in the rest of the sessions. The evidence found demonstrates that men have higher lactate production. Specifically, Mochizuki et al. (2020) (Mochizuki et al., 2022) reported that blood lactate concentration immediately after exercise was significantly higher in men than in women, although these results were not significant. On the other hand, Szivak et al. (2022) (Szivak et al., 2013) indicated that blood lactate concentration was significantly higher in men than in women after strength training. This might be attributed to a constraining phosphorylase function in women, possibly stemming from either a reduced maximal velocity or an elevated Michaelis constant for the enzyme, or diminished levels of alternative activators like cAMP (Esbjornsson-Liljedahl et al., 1999). These results contrast with the significant association observed in the second session at 50% of 1RM obtained in our article but align with the results obtained in the other three sessions where there is no association between sex and lactate production.

Regarding the relationship between age and lactate production, research has shown that lactate production tends to be higher in older individuals. Our findings are supported by those published by Jansson et al. (1994) (Jansson et al., 1994), who stated many years ago that lactate levels in obese men were significantly higher than those in lean males. This is because white adipocytes produce large amounts of lactate (Petersen et al., 2017). Additionally, in a more recent study, Okano et al. (2022) (Okano et al., 2022) indicated that for every incremental increase in body fat

ratio, a 0.157 mmol/L increase in blood lactate level can be expected ($p = 0.001$), further reinforcing the positive relationship between BMI and lactate production.

Finally, older adults tend to exhibit higher lactate production during and after exercise compared to their younger counterparts. To the best of our knowledge, there are no papers comparing lactate production between young and older adults during and after resistance training. However, despite this, there are a few articles that corroborate our findings. Firstly, Seals et al. (1984) (Seals et al., 1984) found that endurance training resulted in adaptations in the blood lactate response to submaximal exercise in older individuals. Masuda et al. (2009) (Masuda et al., 2009) suggested that aging causes metabolic changes in skeletal muscle that can reduce lactate accumulation during exercise and increase fatigue resistance. Tzankoff & Norris (1979) (Tzankoff & Norris, 1979) observed an age-related decrease in the ability to diffuse lactate from muscle and distribute it into its space, potentially affecting endurance and work capacity. Finally, Hermansen (1971) (Hermansen, 1971) highlighted lactate production as an indicator of anaerobic processes during exercise. Collectively, these papers suggest that age-related physiological changes in muscle metabolism contribute to higher lactate production in older adults during and after exercise.

Despite the significant findings of this study, it is important to acknowledge some limitations that may influence the interpretation of the results. Firstly, the sample consisted exclusively of young, healthy adults, limiting the generalizability of the findings to populations with different demographic characteristics. Additionally, the study specifically focused on two squat training protocols, which may not fully reflect the complexity of metabolic responses in other exercises or training modalities.

The results of this study have practical implications for strength training prescription in different populations. Firstly, they suggest that individuals with higher levels of physical activity may experience an improvement in lactate metabolism efficiency, which can have a positive impact on performance and recovery. This supports the importance of including strength training in physical activity programs to promote beneficial metabolic adaptations. Additionally, the identification of sex disparities in lactate production highlights the need to consider differentiated training strategies for men and women.

Conclusions

In summary, this study provides valuable insight into the association between lactate production and PAL in young, healthy adults undergoing different squat training protocols. The findings suggest that intense physical activity may be related to lower lactate production, indicating greater metabolic efficiency. Additionally, sex differences in metabolic response were observed, emphasizing the importance of personalized approaches in program design. These results contribute to the growing body of knowledge in the field of strength training and provide useful information for optimizing physical performance in diverse populations. However, it is crucial to consider the study's limitations when interpreting and applying these findings. Future research could address these limitations and continue to expand our understanding of metabolic responses to strength training.

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ADDITIONAL INFORMATION AND DECLARATIONS

Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions

X lead the project, the methodology design, data collection, and the manuscript writting. X contribute to data analysis and manuscript review. X revised the manuscript critically. All authors read and approved the final version of the manuscript. All authors read and approved the final version of the manuscript.

401 ## References

402 Beneke, R., Leithäuser, R. M., & Ochentel, O. (2011). Blood lactate diagnostics in exercise
403 testing and training. *International Journal of Sports Physiology and Performance*, *6*(1), 8–
404 24. https://doi.org/10.1123/ijspp.6.1.8
405 Bisdee, J. T., James, W. P. T., & Shaw, M. A. (1989). Changes in energy expenditure during the
406 menstrual cycle. *British Journal of Nutrition*, *61*(2), 187–199.
407 https://doi.org/10.1079/bjn19890108
408 Brown, L. E. (2007). *Strength training*. Human Kinetics.
409 Chmielewska, A., Kujawa, K., & Regulska-Ilow, B. (2023). Accuracy of Resting Metabolic Rate
410 Prediction Equations in Sport Climbers. *International Journal of Environmental Research*
411 *and Public Health*, *20*(5), 4216. https://doi.org/10.3390/ijerph17217777
412 Comfort, P., & Kasim, P. (2007). Optimizing squat technique. *Strength and Conditioning*
413 *Journal*, *29*(6), 10–13. https://doi.org/10.1519/00126548-200712000-00001
414 Crotty, N. M., Boland, M., Mahony, N., Donne, B., & Fleming, N. (2021). Reliability and validity
415 of the Lactate Pro 2 Analyzer. *Measurement in Physical Education and Exercise Science*,
416 *25*(3), 202–211. https://doi.org/doi.org/10.1080/1091367X.2020.1865966
417 Davis, J. A. (1985). Anaerobic threshold: review of the concept and directions for future
418 research. *Medicine and Science in Sports and Exercise*, *17*(1), 6–21.
419 Del-Cuerpo, I., Jerez-Mayorga, D., Chirosa-Ríos, L. J., Morenas-Aguilar, M. D., Mariscal-Arcas,
420 M., López-Moro, A., & Delgado-Floody, P. (2023). Males Have a Higher Energy
421 Expenditure than Females during Squat Training. *Nutrients*, *15*(15), 3455.
422 https://doi.org/10.3390/nu15153455
423 del-Cuerpo, I., Jerez-Mayorga, D., Delgado-Floody, P., Morenas-Aguilar, M. D., & Chirosa-Ríos,
424 L. J. (2023). Test–Retest Reliability of the Functional Electromechanical Dynamometer for
425 Squat Exercise. *International Journal of Environmental Research and Public Health*, *20*(2),
426 1289. https://doi.org/10.3390/ijerph20021289
427 Dominguez, R., Maté-Muñoz, J. L., Serra-Paya, N., & Garnacho-Castaño, M. V. (2018). Lactate
428 threshold as a measure of aerobic metabolism in resistance exercise. *International Journal*
429 *of Sports Medicine*, *39*(03), 163–172. https://doi.org/10.1055/s-0043-122740
430 Esbjornsson-Liljedahl, M., Sundberg, C. J., Norman, B., & Jansson, E. (1999). Metabolic
431 response in type I and type II muscle fibers during a 30-s cycle sprint in men and women.
432 *Journal of Applied Physiology*, *87*(4), 1326–1332.
433 https://doi.org/10.1519/JSC.0b013e318259e009
434 Garnacho-Castaño, M. V, Dominguez, R., & Maté-Muñoz, J. L. (2015). Understanding the
435 meaning of lactate threshold in resistance exercises. *International Journal of Sports*
436 *Medicine*, 371–377. https://doi.org/10.1055/s-0034-1398495
437 Hedrick, A. (1993). STRENGTH TRAINING: Literature Review: High Speed Resistance
438 Training. *Strength & Conditioning Journal*, *15*(6), 22–30.
439 Hermansen, L. (1971). Lactate production during exercise. *Muscle Metabolism During Exercise:*
440 *Proceedings of a Karolinska Institutet Symposium Held in Stockholm, Sweden, September*
441 *6–9, 1970 Honorary Guest: E Hohwü Christensen*, 401–407.
442 https://doi.org/https://doi.org/10.1007/978-1-4613-4609-8_36
443 Hettinger, T. (2017). *Physiology of strength*. Pickle Partners Publishing.

444 Hood, M. S., Little, J. P., Tarnopolsky, M. A., Myslik, F., & Gibala, M. J. (2011). Low-volume
445 interval training improves muscle oxidative capacity in sedentary adults. *Medicine and*
446 *Science in Sports and Exercise*, *43*(10), 1849–1856.
447 https://doi.org/10.1249/MSS.0b013e3182199834
448 Hu, M., Finni, T., Zou, L., Perhonen, M., Sedliak, M., Alen, M., & Cheng, S. (2009). Effects of
449 strength training on work capacity and parasympathetic heart rate modulation during
450 exercise in physically inactive men. *International Journal of Sports Medicine*, 719–724.
451 https://doi.org/10.1055/s-0029-1225329. Epub 2009 Aug 14.
452 Jansson, P. A., Larsson, A., Smith, U., & Lönnroth, P. (1994). Lactate release from the
453 subcutaneous tissue in lean and obese men. *The Journal of Clinical Investigation*, *93*(1),
454 240–246. https://doi.org/10.1172/JCI116951
455 Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic
456 fitness. *Sports Medicine*, *29*, 373–386. https://doi.org/10.2165/00007256-200029060-
457 00001
458 Jones, L. M., Stoner, L., Baldi, J. C., & McLaren, B. (2020). Circuit resistance training and
459 cardiovascular health in breast cancer survivors. *European Journal of Cancer Care*, *29*(4).
460 https://doi.org/10.1111/ecc.13231
461 Kantanista, A., Kusy, K., Pospieszna, B., Korman, P., Wieliński, D., & Zieliński, J. (2021).
462 Combined analysis of blood ammonia and lactate levels as a practical tool to assess the
463 metabolic response to training sessions in male and female sprinters. *The Journal of*
464 *Strength & Conditioning Research*, *35*(9), 2591–2598.
465 https://doi.org/10.1519/JSC.0000000000003193
466 Lee, S., Choi, Y., Jeong, E., Park, J., Kim, J., Tanaka, M., & Choi, J. (2023). Physiological
467 significance of elevated levels of lactate by exercise training in the brain and body. *Journal*
468 *of Bioscience and Bioengineering*. https://doi.org/10.1016/j.jbiosc.2022.12.001
469 Lo, O.-Y., Kahya, M., & Manor, B. (2022). Powering Through Daily Activities in Older Age—Will
470 Power Training Replace Strength Training in Later Life? *JAMA Network Open*, *5*(5),
471 e2211631–e2211631. https://doi.org/10.1001/jamanetworkopen.2022.11631
472 Lopes, F. A. S., Panissa, V. L. G., Julio, U. F., Menegon, E. M., & Franchini, E. (2014). The
473 effect of active recovery on power performance during the bench press exercise. *Journal of*
474 *Human Kinetics*, *40*, 161. https://doi.org/10.2478/hukin-2014-0018
475 Masuda, S., Hayashi, T., Egawa, T., & Taguchi, S. (2009). Evidence for differential regulation of
476 lactate metabolic properties in aged and unloaded rat skeletal muscle. *Experimental*
477 *Gerontology*, *44*(4), 280–288. https://doi.org/doi.org/10.1016/j.exger.2008.12.003
478 Messias, L. H. D., Gobatto, C. A., Beck, W. R., & Manchado-Gobatto, F. B. (2017). The lactate
479 minimum test: Concept, methodological aspects and insights for future investigations in
480 human and animal models. *Frontiers in Physiology*, *8*, 389.
481 https://doi.org/10.3389/fphys.2017.00389
482 Messonnier, L. A., Emhoff, C.-A. W., Fattor, J. A., Horning, M. A., Carlson, T. J., & Brooks, G. A.
483 (2013). Lactate kinetics at the lactate threshold in trained and untrained men. *Journal of*
484 *Applied Physiology*, *114*(11), 1593–1602. https://doi.org/10.1152/japplphysiol.00043.2013
485 Messonnier, L., Freund, H., Féasson, L., Prieur, F., Castells, J., Denis, C., Linossier, M.-T.,
486 Geyssant, A., & Lacour, J.-R. (2001). Blood lactate exchange and removal abilities after

relative high-intensity exercise: effects of training in normoxia and hypoxia. *European Journal of Applied Physiology*, *84*, 403–412. https://doi.org/10.1007/s004210000378

Mochizuki, Y., Saito, M., Homma, H., Inoguchi, T., Naito, T., Sakamaki-Sunaga, M., & Kikuchi, N. (2022). *Sex differences in lifting velocity and blood lactate concentration during resistance exercise using different rest intervals*. https://doi.org/10.21203/rs.3.rs-1288068/v1

Okano, S., Nishizawa, H., Yui, J., & Nakamura, A. (2022). Impact of body fat, body water content, and skeletal muscle mass index on peak salivary lactate levels after squat jump exercise in healthy non-athlete adult males. *BMC Sports Science, Medicine and Rehabilitation*, *14*(1), 91. https://doi.org/doi.org/10.1186/s13102-022-00482-6

Pesta, D., Hoppel, F., Macek, C., Messner, H., Faulhaber, M., Kobel, C., Parson, W., Burtscher, M., Schocke, M., & Gnaiger, E. (2011). Similar qualitative and quantitative changes of mitochondrial respiration following strength and endurance training in normoxia and hypoxia in sedentary humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *301*(4), R1078–R1087. https://doi.org/10.1152/ajpregu.00285.2011

Petersen, C., Nielsen, M. D., Andersen, E. S., Basse, A. L., Isidor, M. S., Markussen, L. K., Viuff, B. M., Lambert, I. H., Hansen, J. B., & Pedersen, S. F. (2017). MCT1 and MCT4 expression and lactate flux activity increase during white and brown adipogenesis and impact adipocyte metabolism. *Scientific Reports*, *7*(1), 13101. https://doi.org/10.1038/s41598-017-13298-z

Rodriguez-Perea, A., Jerez-Mayorga, D., García-Ramos, A., Martínez-García, D., & Chirosa Rios, L. J. (2021). Reliability and concurrent validity of a functional electromechanical dynamometer device for the assessment of movement velocity. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *235*(3), 176–181. https://doi.org/10.1177/1754337120984883

Roman-Viñas, B., Serra-Majem, L., Hagströmer, M., Ribas-Barba, L., Sjöström, M., & Segura-Cardona, R. (2010). International physical activity questionnaire: reliability and validity in a Spanish population. *European Journal of Sport Science*, *10*(5), 297–304. https://doi.org/10.1080/17461390903426667

Schlegel, P., & Fialová, D. (2021). Deep Squat–Should We Be Afraid? *Studia Sportiva*, *15*(1), 26–33. https://doi.org/10.5817/StS2021-1-3

Seals, D. R., Hurley, B. F., Schultz, J., & Hagberg, J. M. (1984). Endurance training in older men and women II. Blood lactate response to submaximal exercise. *Journal of Applied Physiology*, *57*(4), 1030–1033. https://doi.org/10.1152/jappl.1984.57.4.1030

Szivak, T. K., Hooper, D. R., Dunn-Lewis, C., Comstock, B. A., Kupchak, B. R., Apicella, J. M., Saenz, C., Maresh, C. M., Denegar, C. R., & Kraemer, W. J. (2013). Adrenal cortical responses to high-intensity, short rest, resistance exercise in men and women. *The Journal of Strength & Conditioning Research*, *27*(3), 748–760. https://doi.org/10.1519/JSC.0b013e318259e009

Tzankoff, S. P., & Norris, A. H. (1979). Age-related differences in lactate distribution kinetics following maximal exercise. *European Journal of Applied Physiology and Occupational Physiology*, *42*, 35–40. https://doi.org/https://doi.org/10.1007/BF00421102

Westcott, W. L. (2012). Resistance training is medicine: effects of strength training on health. *Current Sports Medicine Reports*, *11*(4), 209–216. https://doi.org/10.1249/JSR.0b013e31825dabb8

Zatsiorsky, V. M., Kraemer, W. J., & Fry, A. C. (2020). *Science and practice of strength training*. Human Kinetics.

Figure 1

Figure 1. Protocol measurement of the squat exercise

Table 1(on next page)

Table. Descriptive characteristics of the sample based on PAL

PAL: physical activity level; SD: standard deviation.

Table 1. Descriptive characteristics of the sample based on PAL.

50th percentile	Total Mean (SD)	Low PAL (n=15) Mean (SD)	High PAL (n=14) Mean (SD)	Sig.	F value
Age	24.93 (4.56)	25.13 (4.10)	24.71 (5.15)	0.810	0.06
Size	1.70 (0.10)	1.69 (0.10)	1.71 (0.09)	0.645	0.22
Weight	68.05 (12.92)	69.02 (14.71)	67.02 (11.14)	0.685	0.17
BMI	23.48 (2.97)	23.99 (3.30)	22.93 (2.58)	0.343	0.93
Low-PAL (days/week)	4.72 (2.85)	4.20 (3.19)	5.29 (2.43)	0.314	1.05
Low-PAL (minutes/week)	37.93 (36.49)	38.67 (41.21)	37.14 (32.21)	0.913	0.01
Moderate-PAL (days/week)	2.52 (2.32)	2.13 (2.36)	2.93 (2.30)	0.367	0.84
Moderate-PAL (minutes/week)	66.03 (78.52)	48.67 (64.43)	84.64 (89.92)	0.224	1.55
Vigorous-PAL (days/week)	3.69 (1.56)	2.47 (1.13)	5.00 (0.55)	0.000	57.74
Vigorous-PAL (minutes/week)	90.52 (37.59)	84.00 (45.44)	97.50 (26.80)	0.343	0.93

PAL: physical activity level; SD: standard deviation.

Table 2(on next page)

Table 2. Delta change immediately and 10 minutes post-squat exercise.

*: p≤0.05; ImmPost: immediately post; 1RM: one repetition maximum; S1: session 1; S2: session 2.

1 **Table 2**. Delta change immediately and 10 minutes post-squat exercise.

50th percentile	Low-PAL Mean (SD)	High-PAL Mean (SD)	Sig.	F value
Delta ImmPost 50% 1RM S1	8.73 (0.73)	6.86 (2.70)	0.097	2.95
Delta ImmPost 50% 1RM S2	8.85 (3.12)	6.89 (2.36)	0.068	3.62
Delta ImmPost 75% 1RM S1	5.66 (2.86)	3.69 (2.31)	0.050*	4.15
Delta ImmPost 75% 1RM S2	4.16 (2.26)	3.94 (1.61)	0.770	0.09
Delta $Post_{10min}$ 50% 1RM S1	6.52 (3.28)	4.11 (2.26)	0.030*	5.25
Delta $Post_{10min}$ 50% 1RM S2	6.27 (6.27)	4.39 (2.44)	0.059	3.88
Delta $Post_{10min}$ 75% 1RM S1	2.40 (2.40)	1.53 (1.05)	0.107	2.79
Delta $Post_{10min}$ 75% 1RM S2	2.23 (2.23)	1.64 (1.05)	0.201	1.72

2 *: $p \leq 0.05$; ImmPost: immediately post; 1RM: one repetition maximum; S1: session 1; S2: session 2.

3

Table 3(on next page)

Table 3. Association of lactate delta changes immediately post-squat test with PAL.

*: p≤0.05; 95% CI: 95% confidence interval; SE: standard error; PAL: physical activity level.

Table 3. Association of lactate delta changes immediately post-squat test with PAL.

	50% 1RM S1			50% 1RM S2		
	β (95%CI)	**Beta (SE)**	**P-value**	**β (95%CI)**	**Beta (SE)**	**P-value**
Age (years)	0.08 (-0.19; 0.34)	0.11 (0.13)	0.559	0.06 (-0.18; 0.30)	0.09 (0.12)	0.617
Sex (men ref)	-0.79 (-4.09; 2.51)	-0.13 (1.60)	0.627	3.02 (0.05; 5.99)	0.53 (1.44)	0.047*
BMI (kg/m^2)	0.30 (-0.50; 1.10)	0.29 (0.39)	0.447	0.97 (0.25; 1.69)	0.99 (0.35)	0.011*
Body fat (kg)	0.07 (-0.36; 0.50)	0.12 (0.21)	0.750	-0.38 (-0.77; 0.01)	-0.69 (0.19)	0.055
Vigorous PAL (MET)	0.00 (0.00; 0.00)	-0.21 (0.00)	0.282	0.00 (0.00; 0.00)	-0.22 (0.00)	0.223
	75% 1RM S1			**75% 1RM S2**		
	β (95%CI)	**Beta (SE)**	**P-value**	**β (95%CI)**	**Beta (SE)**	**P-value**
Age (years)	-0.21 (-0.46; 0.05)	-0.34 (0.12)	0.111	0.19 (0.02; 0.36)	0.44 (0.08)	0.032*
Sex (men ref)	-2.41 (-5.60; 0.78)	-0.44 (1.54)	0.132	0.28 (-1.83; 2.39)	0.07 (1.02)	0.785
BMI (kg/m^2)	-0.23 (-1.01; 0.54)	-0.25 (0.37)	0.545	0.34 (-0.17; 0.85)	0.52 (0.25)	0.186
Body fat (kg)	0.21 (-0.20; 0.63)	0.41 (0.20)	0.302	-0.13 (-0.41; 0.14)	-0.36 (0.13)	0.328
Vigorous PAL (MET)	0.00 (0.00; 0.00)	-0.17 (0.00)	0.401	0.00 (0.00; 0.00)	-0.13 (0.00)	0.481

1*: p≤0.05; 95% CI: 95% confidence interval; SE: standard error; PAL: physical activity level.

2

Table 4(on next page)

Table 4. Association of lactate delta changes 10 minutes post-squat test with PAL.

*: p≤0.05; 95% CI: 95% confidence interval; SE: standard error; PAL: physical activity level.

Table 4. Association of lactate delta changes 10 minutes post-squat test with PAL.

	50% 1RM S1			50% 1RM S2		
	β (95%CI)	**Beta (SE)**	**P-value**	**β (95%CI)**	**Beta (SE)**	**P-value**
Age (years)	0.18 (-0.08; 0.44)	0.27 (0.13)	0.170	0.05 (-0.19; 0.28)	0.08 (0.11)	0.692
Sex (men ref)	-0.1 (-3.35; 3.12)	-0.02 (1.57)	0.942	1.63 (-1.31; 4.57)	0.31 (1.42)	0.262
BMI (kg/m^2)	0.35 (-0.44; 1.13)	0.34 (0.38)	0.372	0.47 (-0.25; 1.18)	0.52 (0.35)	0.189
Body fat (kg)	-0.03 (-0.45; 0.40)	-0.05 (0.20)	0.895	-0.19 (-0.57; 0.20)	-0.37 (0.19)	0.321
Vigorous PAL (MET)	0.00 (0.00; 0.00)	-0.32 (0.00)	0.096*	-0.01 (-0.02; 0.00)	-0.39 (0.00)	0.046*
	75% 1RM S1			**75% 1RM S2**		
	β (95%CI)	**Beta (SE)**	**P-value**	**β (95%CI)**	**Beta (SE)**	**P-value**
Age (years)	0.01 (-0.14; 0.15)	0.02 (0.06)	0.913	0.07 (-0.03; 0.17)	0.25 (0.05)	0.176
Sex (men ref)	0.55 (-1.23; 2.33)	0.19 (0.86)	0.532	0.14 (-1.09; 1.36)	0.06 (0.59)	0.821
BMI (kg/m^2)	0.25 (-0.18; 0.69)	0.52 (0.21)	0.236	0.27 (-0.03; 0.57)	0.65 (0.14)	0.075*
Body fat (kg)	-0.10 (-0.33; 0.13)	-0.36 (0.11)	0.393	-0.06 (-0.06; 0.22)	-0.27 (0.08)	0.424
Vigorous PAL (MET)	0.00 (0.00; 0.00)	-0.08 (0.00)	0.704	0.00 (0.00; 0.00)	-0.13 (0.00)	0.131

1*: p≤0.05; 95% CI: 95% confidence interval; SE: standard error; PAL: physical activity level.

2