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High School Athlete Optimal Warm-Up Time

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ABSTRACT

Objective The purpose was to determine the amount of time required for muscles to reach peak temperature in order to prevent muscle injury and maximize muscle readiness. This information will inform players and coaches as well as inspire further research.

Methods This study investigated the optimal warm-up duration for high school tennis athletes using a dynamic jump roping warm-up. 14 participants (9 female, 5 male; mean age = 16.14 years) were tested as temperature changes in the gastrocnemius and soleus lower leg muscles were recorded in 30-second intervals.

Results All participants reached peak muscle temperature within 150 seconds, with an average peak time of 109 seconds. The mean baseline temperature was 32.14°C, increasing to an average peak of 33.11°C, representing a mean increase of 0.97°C. Most participants (n=5) reached peak temperature at 120 seconds. Statistical analysis revealed a significant increase in temperature ($p = 0.0202$), suggesting that the observed changes were not due to chance.

Conclusion These findings indicate that a dynamic warm-up of approximately 2 minutes is sufficient to achieve maximal muscle warming in high school tennis athletes. Extending the warm-up beyond this duration did not result in additional temperature increases and may contribute to unnecessary fatigue.

Keywords: Warm-up; infrared thermography; muscle temperature; tennis; high school athletes

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Introduction

Warming up before athletic activity is essential before engaging in competitive sports or physical activity. The benefits of warming up include injury prevention, increased blood flow, enhanced flexibility, and overall enhanced performance (Fradkin et al., 2010; López-Samanes et al., 2021; Trovato et al., 2024; Wilson et al., 2025). In high school athletes, sporting events often begin immediately after classes end, leaving little opportunity for athletes to prepare their bodies for play. Jumping rope is a common warm-up activity for tennis players as it warms up both the upper and lower body while elevating heart rate (López-Samanes et al., 2021; Makaruk, 2013). Many studies have looked into the detection of muscle function, but there is currently no data showing the optimal amount of time to warm up before a tennis match (Alburquerque Santana et al., 2022; Al-Nakhli et al., 2012; Côrte et al., 2019; dos Santos Bunn et al., 2020; Fradkin et al., 2010; Hadžić et al., 2019; Trovato et al., 2024). This study will utilize infrared thermographic technology to detect changes in muscle temperature during jump rope warm-up. Infrared thermal imaging is a non-invasive, effective way to measure changes in muscle temperature (Alburquerque Santana et al., 2022; Al-Nakhli et al., 2012; Côrte et al., 2019; dos Santos Bunn et al., 2020; Hadžić et al., 2019; Jung et al., 2021; Marins et al., 2014; Rojas-Valverde et al., 2021; Sanchis-Sánchez et al., 2014; Trovato et al., 2024). The purpose of this study is to identify the length of time it takes to increase muscle temperature and, therefore, blood flow, in high school tennis athletes performing a jump rope warm-up. Using a FLIR camera (forward-looking infrared camera) the temperature change of the lower leg muscles over time in high school tennis athletes will be measured to identify when muscles are adequately warmed for competition. To protect the participants' confidentiality, the high school that the participants attend will be kept confidential and referred to in this study as East High School.

Methods

This experimental study aimed to collect quantitative data from varsity high school tennis athletes from East High School to determine the optimal amount of time a standardized jump rope warm-up would increase muscle temperature to its peak using infrared thermographic imaging to measure the temperature. The purpose of this study is to establish the optimal time to jump rope before

exercise activity which enables muscles to be warmed up. Data was collected using the FLIR-E64501 camera to detect the peak temperature change in the gastrocnemius and soleus lower leg muscles. A regular unweighted jump rope was used by each test subject. The jump rope type remained the same for each participant. Infrared thermographic imaging was chosen due to the abundance of repeated studies that used it as an efficient, non-invasive, and accurate measure of underlying muscle temperature (Alburquerque Santana et al., 2022; Al-Nakhli et al., 2012; Côrte et al., 2019; dos Santos Bunn et al., 2020; Hadžić et al., 2019; Jung et al., 2021; Marins et al., 2014; Rojas-Valverde et al., 2021; Sanchis-Sánchez et al., 2014; Trovato et al., 2024). A standardized jump-rope protocol was selected because it reflects typical warm-ups in agility-based sports such as tennis, where rapid muscle activation of the lower leg is critical. All test subjects stood 4 feet from the camera during the test. All of the participants were tested in the same location in an indoor gymnasium where the temperature was held constant (see Figure 1). The temperature of the leg muscles was measured every 30 seconds for consistency across each participant. This ensured that the temperature change would be identifiable at each interval. The FLIR camera was targeted to the lower leg overlying the gastrocnemius and soleus lower leg muscles. The data was obtained from participants and averaged to accurately measure the amount of time it takes for the lower leg muscles' temperature to increase to its peak (see Figure 2). This signifies the muscle has warmed up, with the max amount of increased temperature in the leg muscles as the indicator.

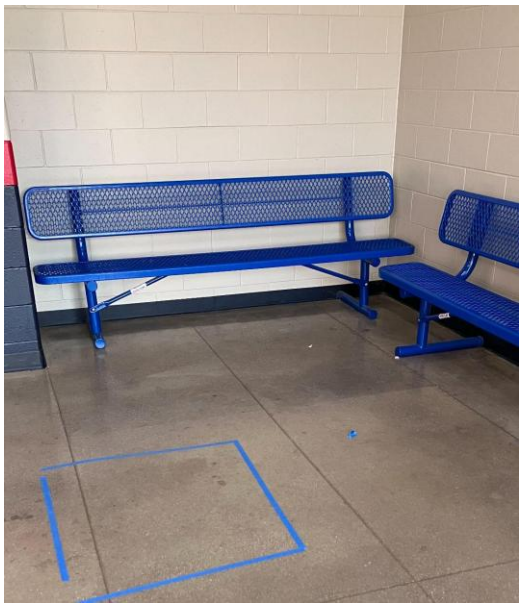


Figure 1. The blue square is where the subject jumped rope



Figure 2. Screenshot of the FLIR camera measuring lower leg temperature (the target reads the highest temperature)

Population

The test subject population was high school boys and girls tennis players from the varsity East High School tennis teams. There a total of 14 test subjects. 9 females were tested, and 5 males were tested. The average age of the subjects was 16.12 years. Jump roping started from a resting state where everyone was confirmed to have not performed any physical activity for at least 18 hours before data was collected. All participants wore attire that exposed their lower leg muscles to ensure accurate readings of temperature.

Results

There were a total of 14 subjects tested: 5 male subjects and 9 female subjects (see Table 1). The participants all jumped rope for at least 180 seconds, and all reached their peak temperature by 150 seconds. 1 subject reached peak temperature at 60 seconds, 4 subjects reached at 90 seconds, 5 subjects reached at 120 seconds, and 3 subjects reached at 150 seconds (see Figure 3).

The average baseline temperature was 32.14 degrees C. The average peak temperature reached was 33.11 degrees C. The average time to reach peak temperature was 109 seconds (see Figure 4). The average temperature change was +0.97 degrees C across all participants.

The range of the baseline temperature was 30.4-33.6 degrees C. The range of the peak temperature reached was 31.3-34.8 degrees C. The range of the temperature change was 0.4-2.1 degrees C. The median baseline temperature was 32.1°C, the median peak temperature was 33.05°C, and the median temperature change was 0.9°C, all of which are close to the means, suggesting the data is relatively symmetric without strong skew or outliers.

The median of the baseline temperature was 32.1 degrees C. The median of the peak temperature was 33.05 degrees C. The median of the temperature change was 0.9 degrees C.

Most of the tested athletes reached their peak temperature at 120 seconds (n=5) (Figure 4).

The average change in temperature was an increase of 0.64 degrees C. The p-value was derived using the one-sample t-test. The p-value of the temperature change was 0.0202 ($p<0.05$), indicating that the results are statistically significant. During the testing of the subjects, there were no injuries sustained by the athletes. The athletes were able to participate without much difficulty or fatigue. There were no camera or mechanical malfunctions.

Table 1. Demographics of Participants

Characteristic	Value
Number of players	14
Age, years	14-18 (Mean=16.14)
Sex Male Female	 5 9
Number of Varsity Tennis Players	14 (100% of subjects)
Tested at the same High School Gymnasium	14 (100% of subjects)

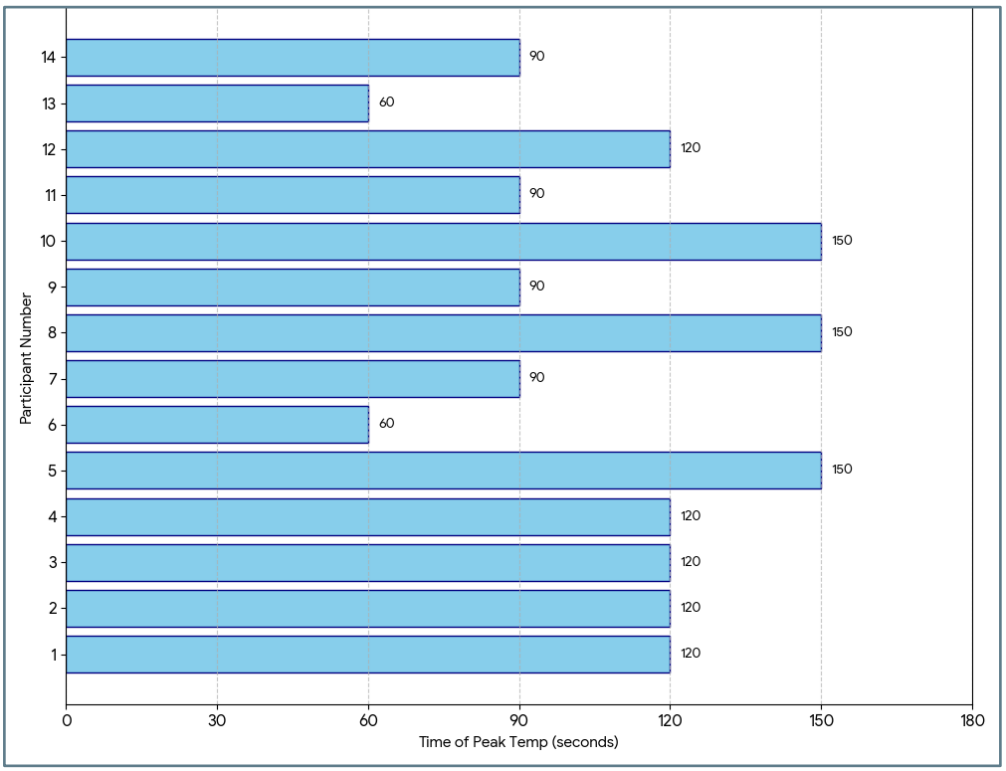


Figure 3. Time to Reach Peak Temperature for Each Participant

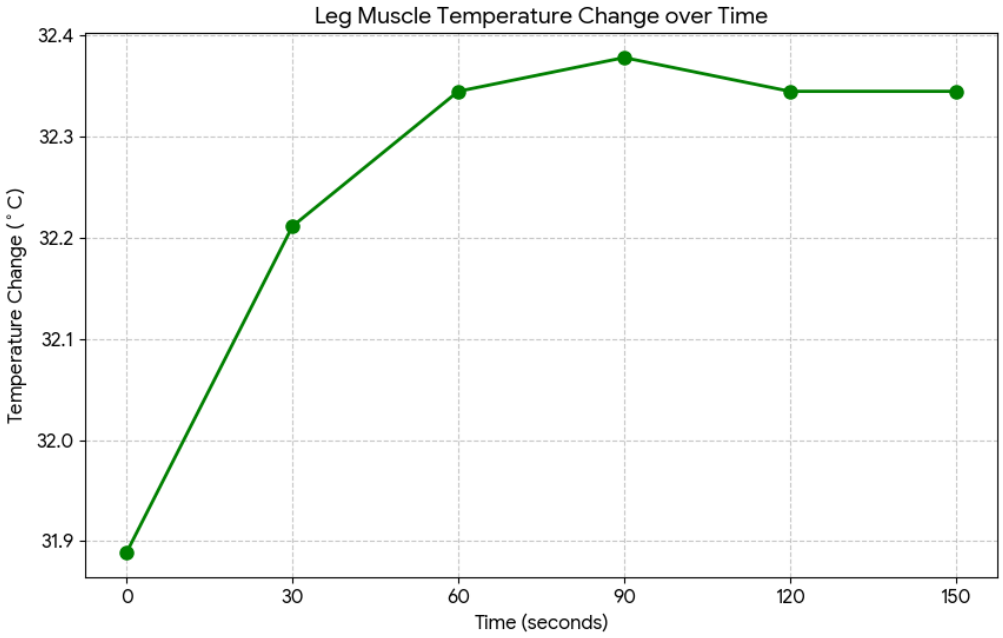


Figure 4. Average Temperature Change of All 14 Subjects over Time

Discussion

In this study, it showed that varsity student athletes reached their optimal warm-up time in an average of 109 seconds. The most frequent time to reach peak

muscle was 120 seconds (mode). Jumping rope for a longer amount of time did not significantly increase the temperature and could lead to fatigue. Given these data points, the study recommended that high school athletes jump rope for 2 minutes prior to engaging in their athletic competition. 2 minutes is a round number that coaches could easily recommend to their players. 2 minutes was also the most frequent time to reach muscle temperature change in the study cohort. Jump roping warm up routine in this study should be recommended to high school tennis players to use prior to their competition. This data could also be extrapolated to other sports using the lower leg muscles such as basketball, football, or soccer. Many of these other sports also have limited time to warm up after classes and before the start of their athletic competition.

This cohort was specific to high school varsity tennis athletes, thus including higher-level high school athletes who perform in a sport that requires lower extremity dynamic and lateral movements. Only varsity athletes were used to include a cohort of higher-level athletes. At this specific high school, the girls' varsity athletes are two-time Division 1 team state defending champions, and the boys commonly send 50-60% of their team to the individual state tournament each year.

Some of the limitations of this study were that possible hydration or prior-day activity differences were not accounted for; however, this study mimics typical tennis match-day conditions. Additionally, the age group was limited to high school-aged athletes. Every athlete tested was comfortable jumping rope; some subjects jumped at different speeds or with different abilities.

The warmups are important to preventing injury and optimizing muscle readiness (Alburquerque Santana et al., 2022; Behm et al., 2023; Côrte et al., 2019; Ding et al., 2022; dos Santos Bunn et al., 2020; Fradkin et al., 2010; Jung et al., 2021; Pizzarro et al., 2024; Sanchis-Sánchez et al., 2014; Tsurubami et al., 2020). Warm-ups prevent injuries by increasing muscle readiness and reducing the risk of strains. Côrte et al. (2019) performed a study using infrared thermographic technology to monitor muscle temperature in athletes and found it helpful to identify areas at higher risk for injury. Similarly, Pizzarro et al. (2024) examined sports injuries among high school athletes and found an overall injury rate of 2.29 per 1,000 exposures and around 6% of them required surgery. Both of these findings emphasize the significant burden of high school sports injuries and the need for prevention strategies. Ding et al. (2022) published a

systematic review that summarizes physiological mechanisms such as temperature, neuromuscular readiness, and range of motion by which dynamic warm-ups reduce injuries and that structured, multifaceted warm-up programs that incorporate strength, balance, and neuromuscular control are effective in reducing injuries in young athletes. This suggests that muscle temperature can be used as an indicator for risk, and prevention strategies can be taken to reduce the number of injuries.

Research also demonstrates that warmups significantly enhance athletic performance. Trovato et al. (2024) used FLIR infrared thermal imaging to evaluate the difference between static and dynamic warm-ups. They found that the dynamic warm-up led to a greater increase in knee temperature due to increased blood flow, highlighting the link between increased muscle temperature and readiness for physical activity. In parallel, Wilson et al. (2025) published a systematic review on the effectiveness of different muscle warm-up strategies involving strength, power, and contraction speed factors. They found that warm-ups generally enhance performance, but the extent was dependent on participant characteristics such as training status or sex. Makaruk (2013) performed a study that aimed to compare the acute effects of jump rope warm ups on jumping abilities in track and field athletes. The study compared jump rope warm-ups to traditional warm-ups and found that the jump rope warm-up protocol significantly improved horizontal jumping distance and height in track and field athletes compared to the athletes who performed the traditional warm-up protocol. Similarly, Tsurubami et al. (2020) provided a randomized crossover design study that tested the influence of warm-up intensity on how quickly and for how long muscle temperature and jump performance were enhanced. It was concluded that moderate to high-intensity warm-ups rapidly increase muscle temperature, with effects lasting up to 10–20 minutes. Collectively, these studies demonstrate that warm-ups optimize athletic performance.

Infrared thermal imaging has emerged as a highly reliable and effective technology to evaluate underlying muscle function. Al-Nakhli et al. (2012) used infrared thermal imaging to detect the onset of muscle soreness by evaluating temperature change 24 hours post-exercise. They showed an increase in muscle temperature 24-48 hours post exercise compared to control muscle temperatures, indicating ongoing inflammation post exercise and correlating with muscle repair and muscle soreness. Jung et al. (2021) used infrared thermal imaging to

detect muscle activation during resistance training, where skin temperature changes were monitored in participants performing various resistance exercises. They found that the muscles that were engaged during exercise showed measurable increases in skin temperature, demonstrating blood flow and activation. The infrared imaging provided a non-invasive way to identify which muscles were being used and to what extent. Additionally, Hadžić et al. (2019) performed a case study on a runner, and tracked skin temperature changes while performing physical activity to see if thermal patterns reflected fatigue. They found that as fatigue developed, localized temperature variations appeared in the working muscles. This indicates a change in blood flow and muscle efficiency associated with fatigue. Each study is a demonstration of the use of infrared thermography to accurately measure both acute and delayed muscle response using underlying muscle temperature, confirming it as a highly reliable and non-invasive method.

Academic institutions could replicate this study design to test addition cohorts of athletes at different levels. This might include college athletes, professional athletes, or junior athletes. This study could also be replicated using subjects in different sports, which require a dynamic warm-up of the leg muscles such as soccer, basketball, or other racket sports.

Conclusion

In conclusion, jumping rope for 2 minutes gives a high school varsity tennis athlete their maximum muscle warm-up temperature. Jumping rope for longer than this period of time does not add increased warming up of the lower leg muscles.

Ethical Approval and Informed Consent

Each subject was required to sign a consent form, or if they were under the age of 18, their parents signed a consent form. This form explained the procedures and physical risks of participating in the study in detail. This form also addressed the privacy and confidentiality of the data collected. The participants remained anonymous because after the data was averaged, it was disposed of and not shared.

References

Alburquerque Santana, P. V., Alvarez, P. D., Felipe da Costa Sena, A., Serpa, T. K., Assis, M. G., Pimenta, E. M., Costa, H. A., Sevilio de Oliveira Junior, M. N., Torres Cabido, C. E., & Veneroso, C. E. (2022). Relationship between infrared thermography and muscle damage markers in physically active men after plyometric exercise. *Journal of Thermal Biology, 104*, Article 103187. https://doi.org/10.1016/j.jtherbio.2022.103187

Al-Nakhli, H. H., Petrofsky, J. S., Laymon, M. S., & Berk, L. S. (2012). The use of thermal infra-red imaging to detect delayed onset muscle soreness. *Journal of Visualized Experiments*, (59), Article e3551. https://doi.org/10.3791/3551

Behm, D. G., Alizadeh, S., Daneshjoo, A., & Konrad, A. (2023). Potential effects of dynamic stretching on injury incidence of athletes: A narrative review of risk factors. *Sports Medicine, 53*(7), 1359–1373. https://doi.org/10.1007/s40279-023-01847-8

Côrte, A. C., Pedrinelli, A., Marttos, A., Souza, I. F. G., Grava, J., & José Hernandez, A. (2019). Infrared thermography study as a complementary method of screening and prevention of muscle injuries: Pilot study. *BMJ Open Sport & Exercise Medicine, 5*(1), Article e000431. https://doi.org/10.1136/bmjsem-2018-000431

Ding, L., Luo, J., Smith, D. M., Mackey, M., Fu, H., Davis, M., & Hu, Y. (2022). Effectiveness of warm-up intervention programs to prevent sports injuries among children and adolescents: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 19*(10), Article 6336. https://doi.org/10.3390/ijerph19106336

dos Santos Bunn, P., Miranda, M. E. K., Rodrigues, A. I., de Souza Sodré, R., Neves, E. B., & Bezerra da Silva, E. (2020). Infrared thermography and musculoskeletal injuries: A systematic review with meta-analysis. *Infrared Physics & Technology, 109*, Article 103435. https://doi.org/10.1016/j.infrared.2020.103435

Fradkin, A. J., Zazryn, T. R., & Smoliga, J. M. (2010). Effects of warming-up on physical performance: A systematic review with meta-analysis. *Journal of Strength and Conditioning Research, 24*(1), 140–148. https://doi.org/10.1519/JSC.0b013e3181c643a0

Hadžić, V., Širok, B., Malneršič, A., & Čoh, M. (2019). Can infrared thermography be used to monitor fatigue during exercise? A case study. *Journal of Sport and Health Science, 8*(1), 89–92. https://doi.org/10.1016/j.jshs.2015.08.002

Jung, H., Seo, J., Seo, K., Kim, D., & Park, S. (2021). Detection of muscle activation during resistance training using infrared thermal imaging. *Sensors, 21*(13), Article 4505. https://doi.org/10.3390/s21134505

López-Samanes, A., Del Coso, J., Hernández-Davó, J. L., Moreno-Pérez, D., Romero-Rodríguez, D., Madruga-Parera, M., Muñoz, A., & Moreno-Pérez, V. (2021). Acute effects of dynamic versus foam rolling warm-up strategies on physical performance in elite tennis players. *Biology of Sport, 38*(4), 595–601. https://doi.org/10.5114/biolsport.2021.101604

Makaruk, H. (2013). Acute effects of rope jumping warm-up on power and jumping ability in track and field athletes. *Polish Journal of Sport and Tourism, 20*(3), 200–204. https://doi.org/10.2478/pjst-2013-0018

Marins, J. C. B., Moreira, D. G., Cano, S. P., Quintana, M. S., Soares, D. D., de Andrade Fernandes, A., da Silva, F. S., Costa, C. M. A., & dos Santos Amorim, P. R. (2014). Time required to stabilize thermographic images at rest. *Infrared Physics & Technology, 65*, 30–35. https://doi.org/10.1016/j.infrared.2014.02.008

Pizzarro, J., Chiang, B., Malyavko, A., Monroig, C., Mehran, N., Ahmed, S. I., & Tabaie, S. (2024). Epidemiology of sports injuries among high school athletes in the United States: Data from 2015

to 2019. *Orthopaedic Journal of Sports Medicine*, *12*(5). https://doi.org/10.1177/23259671241252637

Rojas-Valverde, D., Tomás-Carús, P., Timón, R., Batalha, N., Sánchez-Ureña, B., Gutiérrez-Vargas, R., & Olcina, G. (2021). Short-term skin temperature responses to endurance exercise: A systematic review of methods and future challenges in the use of infrared thermography. *Life*, *11*(12), Article 1286. https://doi.org/10.3390/life11121286

Sanchis-Sánchez, E., Vergara-Hernández, C., Cibrián, R. M., Salvador, R., Sanchis, E., & Codoñer-Franch, P. (2014). Infrared thermal imaging in the diagnosis of musculoskeletal injuries: A systematic review and meta-analysis. *American Journal of Roentgenology, 203*(4), 875–882. https://doi.org/10.2214/AJR.13.11716

Trovato, B., Sortino, M., Petrigna, L., Roggio, F., & Musumeci, G. (2024). The influence of static and dynamic warm-up on knee temperature: Infrared thermography insights before and after a change of direction exercise. *Frontiers in Physiology*, *15*, Article 1393804. https://doi.org/10.3389/fphys.2024.1393804

Tsurubami, R., Oba, K., Samukawa, M., Takizawa, K., Chiba, I., Yamanaka, M., & Tohyama, H. (2020). Warm-up intensity and time course effects on jump performance. *Journal of Sports Science & Medicine, 19*(4), 714–720.

Wilson, C. J., Nunes, J. P., & Blazevich, A. J. (2025). The effect of muscle warm-up on voluntary and evoked force-time parameters: A systematic review and meta-analysis with meta-regression. *Journal of Sport and Health Science, 14*, Article 101024. https://doi.org/10.1016/j.jshs.2025.101024