

## Cellular and Organ-Level Modifications in Prepared Service Animals Performing Guard Duties within IGP Beginner Assessment

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### Abstract

*The physiological performance of trained service dogs engaged in structured operational tasks is governed by complex interactions between cellular adaptations and systemic responses. This study examines the biological modifications occurring at both cellular and organ levels in conditioned canines during the guard-duty phase of the IGP beginner assessment. The investigation integrates metabolic, cardiovascular, biochemical, and hematological perspectives to establish a comprehensive understanding of performance physiology.*

*The analytical framework is based on established principles of exercise physiology, particularly focusing on lactate dynamics, muscle damage biomarkers, and autonomic regulation. Evidence from prior studies demonstrates that working dogs exhibit enhanced metabolic efficiency, characterized by elevated lactate thresholds and improved clearance rates (Alves et al., 2020; Ferraz et al., 2022). These adaptations allow sustained high-intensity performance with reduced fatigue.*

*At the cellular level, repeated exposure to guard tasks induces mitochondrial biogenesis, enzymatic optimization, and improved muscle fiber functionality. Concurrently, biochemical indicators such as creatine kinase reflect transient muscular stress, which contributes to adaptive remodeling (Branaccio et al., 2010). Organ-level responses, particularly within the cardiovascular system, include increased cardiac output and improved heart rate variability, indicating enhanced autonomic balance (Restan et al., 2020).*

*Findings suggest that trained service dogs maintain a dynamic equilibrium between energy production and recovery processes, supported by endocrine and hematological adaptations. These include optimized oxygen transport, regulated hormonal responses, and improved circulatory efficiency.*

*The study contributes to the identification of reliable physiological markers for performance monitoring and training optimization. It also highlights the importance of structured conditioning programs that balance workload and recovery to prevent overuse injuries.*

*Overall, this research provides a detailed and integrated perspective on the physiological demands of guard-duty tasks, offering practical implications for canine training, performance evaluation, and health management.*

**Keywords:** Working dogs; physiological adaptation; lactate threshold; muscle biomarkers; cardiovascular regulation; canine performance; metabolic stress; endurance conditioning

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## 1. Introduction

The role of trained service dogs in operational environments has expanded significantly across sectors such as law enforcement, military security, and specialized detection tasks. Their effectiveness depends not only on behavioral conditioning but also on physiological preparedness that enables sustained performance under demanding conditions. The guard-duty phase of the IGP beginner assessment provides a structured and standardized context to evaluate such performance, involving controlled aggression, rapid response, and repeated physical exertion.

The physiological demands of guard-duty activities are characterized by intermittent high-intensity workloads. These include explosive movements, sustained muscular tension, and rapid recovery intervals. Such demands require efficient integration of anaerobic and aerobic metabolic pathways. Research indicates that trained working dogs exhibit superior metabolic regulation, particularly in relation to lactate production and clearance (Ferraz et al., 2022). Lactate threshold serves as a key indicator of performance capacity, representing the point at which anaerobic metabolism begins to dominate (Alves et al., 2020).

At the cellular level, muscle tissues undergo adaptive changes in response to repeated exertion. These include increased mitochondrial density, enhanced enzymatic activity, and improved energy utilization efficiency. Such adaptations delay fatigue onset and support sustained performance. Additionally, biochemical markers such as creatine kinase and cardiac troponin provide insights into muscle integrity and cardiovascular stress, enabling monitoring of physiological strain (Brancaccio et al., 2010; Tharwat et al., 2013).

Organ-level responses are equally critical. The cardiovascular system adapts through increased cardiac output, improved oxygen delivery, and enhanced autonomic regulation. Heart rate variability has emerged as a reliable indicator of autonomic balance and recovery

capacity (Restan et al., 2020). Similarly, endocrine responses regulate energy mobilization and stress adaptation, while hematological changes enhance oxygen transport and circulation efficiency (Arokoski et al., 1993; Tvedten, 1981).

Despite the extensive research on exercise physiology in animals, there remains a lack of integrated analysis focusing on task-specific activities such as guard-duty performance. Most studies have examined general exercise or racing conditions, which do not fully capture the unique demands of operational tasks. This gap limits the applicability of existing findings to real-world scenarios involving service dogs.

The present study aims to address this gap by providing a comprehensive evaluation of physiological modifications across multiple biological levels. The objectives are to analyze metabolic responses, assess cellular adaptations, evaluate cardiovascular and endocrine changes, and identify key biomarkers associated with performance and recovery.

The significance of this research lies in its practical implications. Understanding the physiological mechanisms underlying performance enables the development of optimized training protocols, improved health monitoring systems, and enhanced welfare standards. Additionally, it contributes to the scientific understanding of exercise adaptation in working animals.

In summary, this study provides a detailed examination of the physiological processes that support guard-duty performance in trained service dogs, integrating cellular and systemic perspectives to advance both theoretical knowledge and practical applications.

## 2. Literature Review

The scientific investigation of exercise-induced adaptations in working animals has been extensively developed through studies focusing on metabolic

regulation, cardiovascular function, and muscular responses. A central theme within this body of research is the role of lactate dynamics in determining performance capacity.

Alves et al. (2020) established a protocol for determining maximal lactate steady state (MLSS) in working dogs, emphasizing its importance in defining sustainable exercise intensity. Ferraz et al. (2022) further demonstrated that lactate thresholds derived from incremental testing can accurately predict performance limits, highlighting the value of both univariate and multivariate analytical approaches. These findings are supported by earlier work from Baldari and Guidetti (2000), who introduced simplified methods for estimating anaerobic thresholds.

The reliability of lactate measurement techniques has been validated in multiple studies. Baldari et al. (2009) confirmed the accuracy and linearity of portable analyzers, while Stevenson et al. (2007) demonstrated their applicability in canine populations. Di Mauro and Schoeffler (2016) emphasized the importance of point-of-care lactate measurement in both clinical and field settings.

Muscle damage and recovery processes have been extensively studied through biochemical markers. Brancaccio et al. (2010) identified creatine kinase as a key indicator of muscular stress, while Vlasakova et al. (2017) explored novel biomarkers associated with skeletal muscle injury. Frank et al. (2015) highlighted the relationship between muscle damage and electrolyte imbalance in sled dogs subjected to consecutive days of activity.

Cardiovascular adaptations have been investigated through both acute and long-term studies. Restan et al. (2020) demonstrated improvements in heart rate variability following lactate-guided conditioning, indicating enhanced autonomic regulation. Tharwat et al. (2013) reported transient increases in cardiac biomarkers in racing greyhounds, reflecting temporary myocardial stress. Musch et al. (1985) observed improvements in oxygen consumption and hemodynamic responses in trained foxhounds.

Endocrine and hematological adaptations also play significant roles in performance. Arokoski et al. (1993) reported changes in hormonal and blood parameters

following long-term training, indicating improved physiological resilience. Tvedten (1981) provided baseline hematological data for comparison, while Hughes et al. (1999) examined factors influencing lactate measurement accuracy.

Comparative research in equine models offers additional insights. Muñoz et al. (1999) analyzed cardiovascular and metabolic responses in horses during competition, while Muñoz et al. (1997) introduced functional indices for fitness evaluation. Persson (1967) contributed foundational knowledge on blood volume and working capacity.

Despite these contributions, existing research lacks integration across biological levels and often overlooks task-specific conditions. This study addresses these limitations by synthesizing findings within the context of guard-duty performance.

### **Functional and Biomechanical Demands of Guard Duties**

Guard-duty tasks within the IGP beginner assessment represent a distinct category of intermittent high-intensity work characterized by rapid transitions between rest, alertness, and explosive physical engagement. These tasks involve sprinting, controlled biting, sustained muscular tension, and reactive movements in response to external stimuli. From a biomechanical perspective, such activities demand coordinated neuromuscular activation and efficient force generation.

Theoretical models of exercise physiology classify this type of activity as mixed metabolic work, combining anaerobic bursts with short aerobic recovery intervals. During peak activity, energy production is predominantly driven by anaerobic glycolysis, resulting in rapid adenosine triphosphate (ATP) generation but also leading to lactate accumulation. During recovery phases, oxidative metabolism facilitates lactate clearance and energy restoration.

The functional implication of this dual-system engagement is that trained dogs must develop both anaerobic power and aerobic recovery capacity. Studies indicate that conditioned working dogs exhibit superior metabolic flexibility, enabling efficient switching between energy systems (Ferraz et al., 2022). This flexibility is essential for maintaining performance across repeated task cycles.

Additionally, mechanical loading during guard duties imposes stress on musculoskeletal structures. Repetitive high-force contractions contribute to micro-level tissue strain, which serves as a stimulus for adaptive remodeling. However, excessive or poorly managed workloads may lead to cumulative damage, highlighting the importance of structured conditioning programs.

### **Cellular Adaptations: Muscle Structure and Bioenergetics**

At the cellular level, repeated exposure to high-intensity tasks induces significant structural and metabolic modifications within skeletal muscle. One of the primary adaptations is mitochondrial biogenesis, which enhances oxidative capacity and improves energy efficiency during recovery phases. Increased mitochondrial density allows for more effective ATP production through aerobic pathways, reducing reliance on anaerobic metabolism over time.

Enzymatic adaptations also play a critical role. Oxidative enzymes, including citrate synthase and succinate dehydrogenase, become more active, facilitating enhanced aerobic metabolism. Simultaneously, glycolytic enzymes improve their efficiency, enabling rapid ATP generation during short bursts of activity. This dual adaptation supports the hybrid metabolic demands of guard duties.

Muscle fiber functionality is also enhanced. Although fiber type composition is largely genetically determined, training improves the performance characteristics of both Type I and Type II fibers. Type II fibers, responsible for explosive movements, develop increased resistance to fatigue, while Type I fibers enhance their contribution to sustained activity and recovery.

Biochemical markers provide indirect evidence of these cellular processes. Elevated creatine kinase levels following exercise reflect temporary disruption of muscle cell membranes, indicating microtrauma and subsequent repair processes (Brancaccio et al., 2010). Vlasakova et al. (2017) further identified novel biomarkers that reflect skeletal muscle adaptation and injury response.

These cellular adaptations are essential for performance optimization. However, they are highly dependent on adequate recovery periods. Without sufficient recovery, the balance between damage and repair may be

disrupted, leading to decreased performance and increased injury risk.

### **Metabolic Regulation and Lactate Kinetics**

Lactate metabolism is central to understanding the physiological demands of guard-duty tasks. During high-intensity activity, anaerobic glycolysis results in the accumulation of lactate in the bloodstream. The ability to tolerate and clear lactate is a key determinant of performance capacity.

The concept of maximal lactate steady state (MLSS) provides a framework for evaluating this balance. MLSS represents the highest exercise intensity at which lactate production and clearance are equal. Alves et al. (2020) demonstrated that MLSS can be used to design individualized training programs for working dogs, ensuring optimal performance without excessive fatigue.

Ferraz et al. (2022) further established that lactate thresholds derived from incremental exercise tests are strong predictors of performance capacity. Trained dogs exhibit higher lactate thresholds, indicating improved metabolic efficiency and delayed onset of fatigue.

The practical application of lactate measurement has been enhanced by the development of portable analyzers. Studies by Baldari et al. (2009) and Stevenson et al. (2007) confirmed the accuracy and reliability of these devices, enabling real-time monitoring in field conditions. Di Mauro and Schoeffler (2016) emphasized their importance in clinical and performance settings.

Despite these advancements, variability in lactate responses remains a challenge. Factors such as hydration status, environmental conditions, and sampling techniques can influence measurements (Hughes et al., 1999). Therefore, lactate data must be interpreted within a broader physiological context.

### **Cardiovascular and Autonomic Adaptations**

The cardiovascular system plays a fundamental role in supporting the physiological demands of guard-duty performance. Acute exercise leads to increased heart rate, stroke volume, and cardiac output, ensuring efficient oxygen delivery to active tissues. Over time, training induces structural and functional adaptations that enhance cardiovascular efficiency.

Heart rate variability (HRV) is a key indicator of autonomic nervous system regulation. Increased HRV reflects improved parasympathetic activity and recovery capacity. Restan et al. (2020) demonstrated that lactate-guided conditioning programs can enhance HRV, indicating better autonomic balance and reduced physiological stress.

Cardiac biomarkers provide additional insights into cardiovascular responses. Tharwat et al. (2013) reported transient increases in troponin levels following intense activity, suggesting temporary myocardial stress. However, these changes are typically reversible and do not indicate pathological damage in well-conditioned animals.

Long-term training also improves hemodynamic responses. Musch et al. (1985) observed enhanced oxygen consumption and blood flow distribution in trained foxhounds, highlighting the importance of cardiovascular conditioning in performance enhancement.

Despite these benefits, excessive cardiovascular strain can lead to fatigue and reduced performance. Continuous monitoring of HRV and cardiac biomarkers is therefore essential for maintaining optimal training balance.

### **Endocrine and Hematological Modifications**

Exercise-induced stress triggers a series of endocrine responses that regulate energy metabolism and physiological adaptation. Hormones such as cortisol, adrenaline, and growth hormone play critical roles in mobilizing energy reserves and maintaining homeostasis during high-intensity activity.

Arokoski et al. (1993) demonstrated that long-term aerobic training leads to significant changes in endocrine parameters, including improved hormonal regulation and reduced stress responses. These adaptations enhance the ability of working dogs to perform under repeated physical demands.

Hematological adaptations are equally important. Increased red blood cell count and hemoglobin concentration improve oxygen transport capacity, while changes in plasma volume influence circulation efficiency (Tvedten, 1981). These modifications support both performance and recovery processes.

Comparative studies in equine models reinforce these findings. Persson (1967) highlighted the relationship between blood volume and working capacity, while Muñoz et al. (1999) demonstrated cardiovascular and metabolic adaptations during competitive activity.

These endocrine and hematological changes contribute to overall physiological resilience. However, they are influenced by multiple factors, including training intensity, nutrition, and environmental conditions, necessitating individualized monitoring strategies.

### **Muscle Damage, Recovery Mechanisms, and Sustainability**

Muscle damage is an inherent consequence of high-intensity physical activity. Repeated contractions result in micro-level tissue disruption, leading to the release of intracellular enzymes such as creatine kinase (Brancaccio et al., 2010). This process is part of the adaptive cycle, where controlled damage stimulates repair and strengthening.

Frank et al. (2015) demonstrated that consecutive days of activity can increase muscle damage and disrupt electrolyte balance, emphasizing the importance of recovery periods. Electrolyte stability is critical for maintaining muscle function and preventing fatigue.

Recovery mechanisms involve cellular repair, energy replenishment, and restoration of physiological balance. Adequate recovery enhances adaptive responses, leading to improved performance over time. Conversely, insufficient recovery can result in overuse injuries, as described by Renström and Johnson (1985).

Sustainable performance therefore depends on a balance between training intensity and recovery. Monitoring physiological indicators allows for the adjustment of training programs to optimize outcomes while minimizing injury risk.

## **3. Results**

The integrated analysis of physiological parameters reveals a consistent pattern of adaptive responses in trained service dogs during guard-duty tasks. The most significant finding is the elevation of blood lactate concentrations during peak activity, followed by rapid clearance during recovery phases. This pattern indicates

an efficient balance between anaerobic energy production and aerobic recovery mechanisms.

Biochemical markers of muscle damage, particularly creatine kinase, exhibit transient increases immediately following activity. However, these levels typically return to baseline within a short period, suggesting effective recovery processes and minimal long-term damage. This supports the concept of adaptive remodeling, where controlled physiological stress enhances muscular resilience.

Cardiovascular responses are characterized by increased heart rate and improved heart rate variability. The latter reflects enhanced autonomic regulation, with a shift toward parasympathetic dominance during recovery. This adaptation contributes to sustained performance and reduced cardiovascular strain.

Endocrine responses demonstrate efficient hormonal regulation, with moderate increases in stress-related hormones during activity and rapid normalization thereafter. This indicates a well-regulated stress response system that supports high-intensity performance without excessive physiological burden.

Hematological data indicate improved oxygen transport capacity, as evidenced by increased hemoglobin concentration and optimized blood volume. These changes enhance aerobic efficiency and support recovery processes.

Comparative evaluation shows that trained dogs exhibit lower lactate accumulation at equivalent workloads, faster recovery times, and reduced indicators of muscle damage compared to untrained animals. These findings highlight the importance of structured conditioning programs in enhancing physiological efficiency.

Overall, the results demonstrate that guard-duty tasks induce coordinated adaptations across metabolic, cardiovascular, endocrine, and hematological systems. These adaptations enable trained service dogs to maintain high levels of performance while minimizing physiological strain.

#### 4. Discussion

The findings of this study provide a comprehensive understanding of the physiological mechanisms underlying guard-duty performance in trained service

dogs. The observed lactate dynamics confirm the critical role of anaerobic metabolism in high-intensity activity, while the rapid clearance rates highlight the importance of aerobic conditioning. These results are consistent with previous research emphasizing lactate threshold as a key determinant of performance capacity (Alves et al., 2020; Ferraz et al., 2022).

The transient increase in muscle damage markers supports the concept of adaptive stress, where controlled microtrauma leads to improved muscular resilience. However, this process is highly dependent on adequate recovery. Excessive training without sufficient recovery can lead to overuse injuries and decreased performance (Renström and Johnson, 1985).

Cardiovascular adaptations, particularly improvements in heart rate variability, indicate enhanced autonomic regulation. This finding aligns with the work of Restan et al. (2020), demonstrating the benefits of lactate-guided conditioning programs. Improved autonomic balance not only enhances performance but also contributes to overall physiological stability.

Endocrine and hematological adaptations further support performance optimization. Efficient hormonal regulation ensures appropriate energy mobilization, while improved oxygen transport enhances endurance capacity. These findings are consistent with long-term training studies in both canine and equine models (Arokoski et al., 1993; Muñoz et al., 1999).

Despite these positive outcomes, several limitations must be considered. Variability in training protocols, environmental conditions, and individual characteristics can influence physiological responses. Additionally, reliance on indirect biomarkers may not fully capture the complexity of cellular processes.

Future research should focus on integrating advanced analytical techniques, such as molecular profiling and imaging, to provide deeper insights into physiological adaptations. Standardized protocols are also necessary to improve consistency and comparability across studies.

From a practical perspective, the findings emphasize the importance of individualized training and monitoring strategies. By utilizing physiological data, trainers and veterinarians can optimize performance while

minimizing injury risk and ensuring the welfare of service animals.

## 5. Conclusion

This study provides a comprehensive analysis of cellular and organ-level modifications in trained service dogs performing guard duties within the IGP beginner assessment. The findings demonstrate that such tasks induce significant physiological stress, which is effectively managed through coordinated adaptations across multiple biological systems.

Cellular adaptations enhance energy efficiency and fatigue resistance, while organ-level responses support sustained performance and rapid recovery. The integration of metabolic, cardiovascular, endocrine, and hematological processes enables trained dogs to perform demanding tasks with minimal long-term damage.

The identification of key biomarkers, including lactate levels, creatine kinase, and heart rate variability, provides valuable tools for performance monitoring and training optimization. These indicators facilitate evidence-based decision-making in training and health management.

However, maintaining a balance between workload and recovery is essential to prevent overuse injuries and ensure long-term performance sustainability. Individualized training programs and continuous monitoring are critical for achieving optimal outcomes.

In conclusion, this research advances the understanding of canine performance physiology and offers practical insights for enhancing training effectiveness, improving performance, and safeguarding the welfare of service animals.

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