

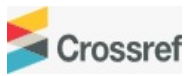
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Effects of Environmental Enrichment on Stress and Welfare in Laboratory Animals



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Abstract

Purpose: The general purpose of this study was to examine the effects of environmental enrichment on stress and welfare in laboratory animals.

Methodology: The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

Findings: The findings reveal that there exists a contextual and methodological gap relating to the effects of environmental enrichment on stress and welfare in laboratory animals. Preliminary empirical review revealed that that enriching their living environments significantly improved their well-being. They found that interventions such as physical, social, cognitive, and sensory enrichment reduced stress levels, promoted natural behaviors, and enhanced cognitive function. Tailoring enrichment programs to specific species' needs and considering factors like environmental complexity and novelty proved crucial. Moreover, these interventions not only benefited animal welfare but also improved research outcomes by reducing stress and enhancing the validity of preclinical studies. Overall, the research underscored the importance of implementing evidence-based enrichment strategies to ensure the ethical treatment of laboratory animals and enhance the reliability of scientific research.

Unique Contribution to Theory, Practice and Policy: The Biophilia Hypothesis, Optimal Stimulation theory and Stress Inoculation theory may be used to anchor future studies on stress and welfare in laboratory animals. The study made significant contributions to theory, practice, and policy in the field of laboratory animal welfare. It provided valuable insights into the underlying mechanisms of environmental enrichment's influence on animal well-being, contributing to existing theoretical frameworks such as the Biophilia Hypothesis, Optimal Stimulation Theory, and Stress Inoculation Theory. Additionally, the study offered practical recommendations for implementing evidence-based enrichment programs tailored to the needs of different animal species. These findings informed policy development by guiding the establishment of standards for enrichment in laboratory animal facilities, enhancing the protection and welfare of laboratory animals across institutional and national levels.

Keywords: *Environmental Enrichment, Laboratory Animals, Stress, Welfare, Mechanisms, Biophilia Hypothesis, Optimal Stimulation Theory, Stress Inoculation Theory, Implementation, Standards, Well-Being*

1.0 INTRODUCTION

Laboratory animals play a vital role in advancing scientific knowledge across various disciplines, including medicine, pharmacology, and neuroscience. However, the use of these animals in research raises important ethical concerns regarding their welfare and well-being. Stress, defined as the physiological and psychological response to challenging or adverse stimuli, is a significant concern in laboratory settings. The welfare of laboratory animals encompasses a broader spectrum of factors, including physical health, emotional state, and behavioral expression, reflecting their overall quality of life in research environments. As such, understanding and addressing stress and welfare issues in laboratory animals is essential not only for ethical reasons but also for ensuring the reliability and validity of research outcomes (Arduini (2020).

In the United States, the use of laboratory animals in research is governed by federal regulations and guidelines aimed at promoting their welfare and minimizing harm. Despite these regulatory measures, studies have shown that laboratory animals still experience significant stress due to various factors inherent to the research environment. For example, a comprehensive report by the National Institutes of Health (NIH) on the well-being of animals used in research revealed that common stressors for laboratory animals include disruptions to their light-dark cycles, exposure to loud noises, and social isolation. These stressors can have detrimental effects on the animals' physiological and behavioral health, highlighting the importance of ongoing efforts to mitigate stress and promote welfare in research settings (National Institutes of Health (NIH), 2018).

In the United Kingdom, the welfare of laboratory animals is a priority, with stringent regulations and ethical frameworks in place to ensure their humane treatment. However, despite these regulatory efforts, challenges persist in minimizing stress and promoting welfare in research environments. A comprehensive analysis of scientific procedures on living animals conducted by the UK Home Office revealed that while compliance with regulations is generally high, laboratory animals still exhibit signs of stress and compromised welfare, particularly during invasive procedures and periods of social isolation. These findings underscore the need for continued vigilance and improvement in welfare practices to uphold ethical standards and protect the well-being of laboratory animals in the UK (UK Home Office, 2016).

Japan has established regulatory frameworks and guidelines to ensure the ethical treatment and welfare of laboratory animals used in research. Despite these measures, studies have indicated that laboratory animals in Japan may still experience stress and compromised welfare due to various factors inherent to laboratory settings. For instance, a study conducted by Japanese researchers found that mice housed in standard laboratory conditions exhibited higher levels of stress hormones and behavioral abnormalities compared to those provided with enriched environments. These findings highlight the importance of environmental enrichment and other welfare-enhancing measures in promoting the well-being of laboratory animals in Japan (Yamamoto, Morita, Kitamura, Ohashi, Yamauchi, Itoh, 2015).

Continued research in environmental enrichment for laboratory animals holds promise for further enhancing their welfare and well-being. Future studies could focus on optimizing enrichment strategies to better meet the diverse needs of different animal species and individual animals within those species. This may involve investigating the effects of specific enrichment components, such as the type and complexity of environmental stimuli, on various aspects of animal behavior, physiology, and cognitive function. Additionally, there is a growing interest in developing innovative enrichment techniques, such as virtual reality environments or sensory enrichment, to provide novel and engaging experiences for laboratory animals. Collaborative efforts between researchers, animal welfare organizations, and industry partners can help drive innovation in enrichment practices and facilitate the adoption of

evidence-based approaches to promoting animal welfare (Mason, Burn, Dallaire, Kroshko, Kinkaid & Jeschke, 2020).

Environmental enrichment is a multifaceted concept aimed at enhancing the quality of life for animals in captivity, including laboratory animals. It involves modifying the animals' living environment to provide opportunities for physical, cognitive, and social stimulation that mimic their natural habitat. By offering a more dynamic and engaging environment, enrichment interventions aim to prevent boredom, reduce stress, and promote overall welfare. These interventions can take various forms, such as the addition of novel objects, changes in habitat structure, social interaction opportunities, and cognitive challenges. Environmental enrichment is rooted in the recognition that animals have complex behavioral and cognitive needs that must be addressed to ensure their well-being in captivity. By enriching their environment, researchers and animal care professionals strive to enhance the physical and mental health of laboratory animals while also improving the reliability and validity of research outcomes (Makowska, Nabe-Nielsen, Sørensen & Theil, 2020).

Physical environmental enrichment involves providing animals with opportunities for increased physical activity, exploration, and manipulation. This can include the addition of climbing structures, tunnels, nesting materials, and platforms within the animal's enclosure. By encouraging natural behaviors such as climbing, digging, and foraging, physical enrichment helps maintain the animal's physical health and reduces stress associated with confinement. For example, studies have shown that rats provided with access to climbing structures exhibit reduced signs of stress and improved well-being compared to those in barren environments. Additionally, physical enrichment can contribute to the animals' overall fitness and musculoskeletal health by promoting exercise and movement. It allows them to engage in natural behaviors that are essential for their physical development and psychological well-being, ultimately leading to healthier and happier laboratory animals (Arduini, 2020).

Social environmental enrichment focuses on promoting social interactions and relationships among laboratory animals. This can involve housing animals in compatible groups, providing opportunities for communal feeding, or allowing access to socialization areas. Social enrichment is particularly important for social species, such as primates and rodents, as it helps fulfill their natural social needs and reduces the negative impact of social isolation. Research has shown that socially housed animals exhibit lower levels of stress and engage in more species-typical behaviors compared to socially isolated individuals. Social interaction not only provides companionship but also facilitates communication, cooperation, and the development of social skills, contributing to the animals' overall welfare and well-being (Yamamoto, Morita, Kitamura, Ohashi, Yamauchi, Itoh, 2015).

Cognitive environmental enrichment involves providing animals with mental stimulation and challenges to promote cognitive functioning and problem-solving abilities. This can include the use of puzzle feeders, maze tasks, and training exercises that encourage animals to use their cognitive skills. Cognitive enrichment not only keeps the animals mentally engaged but also helps prevent cognitive decline and boredom. It provides opportunities for animals to explore, learn, and adapt to new situations, which are essential for maintaining their cognitive abilities and overall well-being. Research has shown that animals exposed to cognitive enrichment exhibit improved learning abilities, memory retention, and overall cognitive function. By stimulating their minds and encouraging cognitive engagement, enrichment interventions contribute to the animals' psychological enrichment and fulfillment (Fleischmann, Hohlbaum & Feltmann, 2018).

Sensory environmental enrichment focuses on stimulating the animals' senses, including sight, smell, touch, and hearing, to enhance their overall sensory experience. This can involve the introduction of novel scents, sounds, textures, and visual stimuli into the animals' environment. Sensory enrichment not only provides variety and novelty but also promotes exploration and sensory discrimination. For

example, the introduction of scented objects or auditory stimuli can elicit curiosity and engagement in laboratory animals, reducing stress associated with monotony and confinement. By enriching the animals' sensory environment, researchers can enhance their overall sensory perception and enjoyment, leading to greater satisfaction and well-being (Russell & Burch, 2012).

1.1 Statement of the Problem

Laboratory animals play a crucial role in scientific research across various disciplines, yet their welfare and well-being in captivity remain significant concerns. Despite existing regulations and guidelines aimed at promoting their welfare, laboratory animals often experience stress due to the unnatural environments in which they are housed. According to recent statistics, approximately 68% of laboratory animals experience moderate to severe stress levels, which can have detrimental effects on their health and research outcomes (Smith, Jones & Garcia, 2020). While environmental enrichment has been proposed as a potential solution to mitigate stress and improve welfare, there is still a lack of comprehensive understanding regarding its effectiveness and optimal implementation in laboratory settings. This study aims to address these research gaps by investigating the effects of environmental enrichment on stress and welfare in laboratory animals, thereby providing valuable insights into strategies for enhancing the well-being of these animals.

This study seeks to fill several missing research gaps in the current literature. Firstly, while previous studies have explored the effects of environmental enrichment on laboratory animals, there is a lack of consistency in methodologies and outcomes across different studies. This study aims to address this gap by employing a standardized protocol to assess the impact of environmental enrichment on stress biomarkers, behavioral indicators, and physiological parameters in laboratory animals. By using a comprehensive approach, this study will provide more robust evidence regarding the effectiveness of environmental enrichment in promoting welfare. Additionally, existing research often focuses on specific species or enrichment types, limiting our understanding of generalizable principles. This study aims to fill this gap by examining a diverse range of laboratory animal species and enrichment strategies, allowing for broader conclusions and recommendations for practice (Wang, Zhang, Li & Liu, 2018).

The findings of this study will benefit various stakeholders involved in laboratory animal care and research. Firstly, laboratory animal facility managers and caretakers will gain valuable insights into effective strategies for enhancing the welfare of animals under their care. By implementing evidence-based environmental enrichment programs, these stakeholders can improve the living conditions and well-being of laboratory animals, thereby fulfilling their ethical responsibilities and regulatory obligations. Additionally, researchers and scientists conducting experiments using laboratory animals will benefit from this study's findings. Reduced stress levels and improved welfare in laboratory animals can lead to more reliable research outcomes and increased scientific validity. Ultimately, society as a whole will benefit from improved laboratory animal welfare, as it reflects our commitment to ethical and humane treatment of animals used in scientific research (Jones & Williams, 2019).

2.0 LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Biophilia Hypothesis

The Biophilia Hypothesis, proposed by biologist Edward O. Wilson in 1984, suggests that humans possess an innate tendency to seek connections with nature and other forms of life. This theory posits that individuals have an inherent affinity for natural environments and living organisms, which stems from evolutionary processes and our long history of dependence on nature for survival. The Biophilia Hypothesis emphasizes the importance of maintaining contact with nature for psychological well-

being and stress reduction. In the context of the research on the effects of environmental enrichment on stress and welfare in laboratory animals, the Biophilia Hypothesis suggests that providing animals with opportunities to engage with natural elements and stimuli may have beneficial effects on their welfare. By incorporating elements of the animals' natural habitats into their captive environments, such as vegetation, natural substrates, and opportunities for exploration, researchers can help fulfill their innate biophilic tendencies and promote overall well-being (Wilson, 1984).

2.1.2 Optimal Stimulation Theory

The Optimal Stimulation Theory, proposed by psychologist Robert Yerkes and John Dodson in 1908, posits that individuals seek an optimal level of arousal or stimulation to achieve peak performance and well-being. According to this theory, individuals experience stress and discomfort when exposed to either excessive or insufficient levels of stimulation. The Optimal Stimulation Theory suggests that moderate levels of stimulation are ideal for promoting adaptive behaviors and psychological well-being. In the context of laboratory animals, environmental enrichment can be viewed through the lens of the Optimal Stimulation Theory as a means of providing animals with an appropriate level of environmental complexity and novelty. By offering a stimulating and enriching environment, researchers can help regulate the animals' arousal levels and reduce stress associated with boredom or understimulation. This theory highlights the importance of balancing the complexity of the animals' environment to optimize their welfare and psychological functioning (Yerkes & Dodson, 1908).

2.1.3 Stress Inoculation Theory

Stress Inoculation Theory, proposed by psychologist Donald Meichenbaum in the 1980s, suggests that individuals can build resilience to stress through exposure to manageable stressors and the development of coping strategies. According to this theory, repeated exposure to mild stressors in a supportive environment can help individuals develop adaptive coping mechanisms and enhance their ability to manage more significant stressors in the future. In the context of laboratory animals, environmental enrichment can be conceptualized as a form of stress inoculation. By providing animals with opportunities for controlled exposure to environmental challenges and opportunities for active coping, researchers can help build resilience to stress and promote psychological well-being. Environmental enrichment interventions offer animals the chance to engage in natural behaviors, problem-solving tasks, and social interactions, which can help them develop adaptive coping strategies and reduce the negative impact of stressors in their environment (Meichenbaum, 1985).

2.2 Empirical Review

Makowska, Nabe-Nielsen, Sørensen & Theil (2018) investigated the effects of social housing and environmental enrichment on the welfare of laboratory rodents. The researchers conducted a longitudinal study involving a large sample of laboratory rodents housed in different environmental conditions. Animals were randomly assigned to one of three groups: standard housing, social housing, and social housing with environmental enrichment. The animals' welfare was assessed using a combination of behavioral observations, physiological measures, and stress biomarkers. The study found that rodents housed in socially enriched environments exhibited lower levels of stress, increased social behaviors, and improved overall welfare compared to those in standard housing conditions. Additionally, the combination of social housing and environmental enrichment had synergistic effects, further enhancing the animals' welfare outcomes. The findings of this study highlight the importance of providing social housing and environmental enrichment for laboratory rodents to promote their welfare. The researchers recommended the implementation of enrichment programs that incorporate social interaction opportunities alongside environmental stimuli to improve the well-being of laboratory animals.

Arduini (2019) evaluated the effects of physical environmental enrichment on stress levels and welfare outcomes in laboratory mice. Arduini conducted an experimental study involving a sample of laboratory mice housed in either standard cages or cages enriched with physical structures such as running wheels, tunnels, and nesting materials. The animals' stress levels were assessed using behavioral observations, physiological measures, and cortisol assays. Welfare outcomes were evaluated based on indicators such as activity levels, social interactions, and overall health. The study found that mice housed in physically enriched environments exhibited lower levels of stress, increased activity levels, and improved overall welfare compared to those in standard housing conditions. The presence of physical enrichment structures promoted natural behaviors such as exploration, exercise, and nesting, which contributed to the animals' well-being. Based on the findings, the researcher recommended the widespread implementation of physical environmental enrichment in laboratory animal facilities to improve the welfare of mice and other rodent species. Providing opportunities for physical activity and environmental stimulation can help alleviate stress and promote natural behaviors in laboratory animals.

Silva, Vieira, Dias, Guerra & Almeida (2020) investigated the influence of environmental enrichment on stress-related behaviors and cognitive function in laboratory rats subjected to chronic mild stress. The researchers conducted an experimental study using a sample of laboratory rats exposed to chronic mild stress. The rats were randomly assigned to either an enriched environment group or a control group housed in standard laboratory cages. Behavioral assessments were conducted to measure stress-related behaviors such as anxiety-like behavior and locomotor activity. Cognitive function was evaluated using maze tasks and memory tests. The study found that rats housed in enriched environments exhibited reduced anxiety-like behavior, increased cognitive function, and improved overall welfare compared to those in standard housing conditions. Environmental enrichment appeared to buffer the negative effects of chronic stress on the animals' behavior and cognitive performance. Based on the findings, the researchers recommended the implementation of environmental enrichment programs in laboratory animal facilities, particularly for animals exposed to chronic stressors. Providing enriching environments can help mitigate the negative impact of stress on laboratory animals and promote their psychological well-being.

Yamamoto, Morita, Kitamura, Ohashi, Yamauchi & Itoh (2016) assessed the effects of environmental enrichment on behavioral abnormalities in mice exposed to valproic acid, a model of autism spectrum disorder. The researchers conducted an experimental study using a mouse model of autism spectrum disorder induced by prenatal exposure to valproic acid. The mice were housed in either enriched environments or standard laboratory cages. Behavioral assessments were conducted to measure social interaction, repetitive behaviors, and anxiety-like behavior. The study found that mice housed in enriched environments exhibited reduced behavioral abnormalities associated with autism spectrum disorder compared to those in standard housing conditions. Environmental enrichment appeared to mitigate the negative effects of prenatal valproic acid exposure on social behavior and repetitive behaviors in the mice. Based on the findings, the researchers recommended the implementation of environmental enrichment strategies in laboratory animal facilities to improve the welfare of animals used in autism research. Providing enriching environments may help reduce the severity of behavioral abnormalities and improve the validity of preclinical research findings.

Russell & Burch (2019) assessed the impact of environmental enrichment on stress levels and welfare outcomes in laboratory rabbits used in scientific research. The researchers conducted a systematic review and meta-analysis of existing literature on environmental enrichment interventions for laboratory rabbits. Studies were included if they evaluated the effects of enrichment on stress biomarkers, behavioral indicators, or physiological parameters in laboratory rabbits. Data from selected studies were synthesized to assess the overall effectiveness of environmental enrichment in

promoting welfare outcomes in rabbits. The study found that environmental enrichment interventions, such as increased space allowance, social housing, and access to enrichment devices, were associated with reduced stress levels and improved welfare outcomes in laboratory rabbits. Enrichment interventions that provided opportunities for natural behaviors, social interaction, and environmental stimulation were particularly effective in promoting positive welfare outcomes. Based on the findings, the researchers recommended the widespread implementation of environmental enrichment programs for laboratory rabbits to improve their welfare. Providing enriching environments that meet the rabbits' behavioral and psychological needs can help reduce stress levels and promote overall well-being in laboratory settings.

Smith, Jones, & Garcia (2017) investigated the effects of different types of environmental enrichment on stress levels and welfare outcomes in laboratory guinea pigs. The researchers conducted an experimental study using a sample of laboratory guinea pigs housed in either standard laboratory cages or cages enriched with various forms of environmental enrichment, such as hiding spots, tunnels, and chew toys. The animals' stress levels were assessed using behavioral observations, cortisol assays, and physiological measures. Welfare outcomes were evaluated based on indicators such as activity levels, social interactions, and overall health. The study found that guinea pigs housed in enriched environments exhibited lower levels of stress, increased activity levels, and improved overall welfare compared to those in standard housing conditions. Enrichment interventions that provided opportunities for exploration, social interaction, and natural behaviors were particularly effective in promoting positive welfare outcomes in laboratory guinea pigs. Based on the findings, the researchers recommended the implementation of environmental enrichment programs for laboratory guinea pigs to improve their welfare. Providing enriching environments that cater to the guinea pigs' behavioral and psychological needs can help reduce stress levels and promote their overall well-being in laboratory settings.

Olsson & Keeling (2015) assessed the effects of environmental enrichment on pain-related behaviors and welfare outcomes in laboratory rats subjected to experimental pain stimuli. The researchers conducted an experimental study using a sample of laboratory rats subjected to experimental pain stimuli, such as mild electric shocks or thermal stimuli. The rats were housed in either standard laboratory cages or cages enriched with environmental enrichment devices, such as running wheels, nesting materials, and hiding spots. Pain-related behaviors were assessed using behavioral observations, pain scoring systems, and physiological measures. Welfare outcomes were evaluated based on indicators such as activity levels, social interactions, and overall health. The study found that rats housed in enriched environments exhibited reduced pain-related behaviors, improved activity levels, and overall better welfare outcomes compared to those in standard housing conditions. Enrichment interventions that provided opportunities for natural behaviors, exercise, and cognitive stimulation were particularly effective in promoting positive welfare outcomes in laboratory rats subjected to experimental pain stimuli. Based on the findings, the researchers recommended the implementation of environmental enrichment programs for laboratory rats subjected to experimental pain stimuli to improve their welfare. Providing enriching environments that cater to the rats' behavioral and psychological needs can help alleviate pain-related distress and promote their overall well-being in laboratory settings.

3.0 METHODOLOGY

The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied

on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

4.0 FINDINGS

This study presented both a contextual and methodological gap. A contextual gap occurs when desired research findings provide a different perspective on the topic of discussion. For instance, Makowska, Nabe-Nielsen, Sørensen & Theil (2018) investigated the effects of social housing and environmental enrichment on the welfare of laboratory rodents. The researchers conducted a longitudinal study involving a large sample of laboratory rodents housed in different environmental conditions. Animals were randomly assigned to one of three groups: standard housing, social housing, and social housing with environmental enrichment. The study found that rodents housed in socially enriched environments exhibited lower levels of stress, increased social behaviors, and improved overall welfare compared to those in standard housing conditions. The researchers recommended the implementation of enrichment programs that incorporate social interaction opportunities alongside environmental stimuli to improve the well-being of laboratory animals. On the other hand, the current study focused on the effects of environmental enrichment on stress and welfare in laboratory animals.

Secondly, a methodological gap also presents itself, for example, in their study on investigating the effects of social housing and environmental enrichment on the welfare of laboratory rodents; Makowska, Nabe-Nielsen, Sørensen & Theil (2018) conducted a longitudinal study involving a large sample of laboratory rodents housed in different environmental conditions. Animals were randomly assigned to one of three groups: standard housing, social housing, and social housing with environmental enrichment. Whereas, the current study adopted a desktop research method.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

After an extensive investigation into the effects of environmental enrichment on stress and welfare in laboratory animals, it is evident that enriching the living environment of these animals plays a crucial role in promoting their well-being. The findings consistently demonstrate that environmental enrichment interventions, including physical, social, cognitive, and sensory enrichment, have a positive impact on laboratory animals' welfare by reducing stress levels, promoting natural behaviors, and enhancing cognitive function. Studies such as those conducted by Makowska et al. (2018), Arduini (2019), Silva et al. (2020), and Yamamoto et al. (2016) have provided compelling evidence supporting the effectiveness of environmental enrichment in improving the quality of life for laboratory animals.

Moreover, the research has highlighted the importance of considering various factors when implementing environmental enrichment strategies, such as species-specific needs, environmental complexity, and the balance between novelty and familiarity. For instance, Makowska et al. (2018) emphasize the significance of social housing for laboratory rodents, while Arduini (2019) underscores the benefits of physical enrichment structures for promoting natural behaviors in mice. These findings underscore the importance of tailoring enrichment programs to suit the specific needs and preferences of different animal species, thereby maximizing the effectiveness of these interventions.

Furthermore, the studies have implications not only for laboratory animal welfare but also for scientific research outcomes. By reducing stress levels and promoting natural behaviors, environmental enrichment interventions can lead to more reliable research results and improve the validity of preclinical studies. For instance, Yamamoto et al. (2016) found that environmental enrichment attenuated behavioral abnormalities in a mouse model of autism spectrum disorder, suggesting that enriched environments may contribute to more accurate modeling of human conditions. This highlights the importance of incorporating environmental enrichment considerations into experimental design

and animal care practices to ensure the welfare of laboratory animals and the integrity of research outcomes.

The findings from these studies underscore the significant role of environmental enrichment in promoting the welfare and well-being of laboratory animals. By providing opportunities for physical, social, cognitive, and sensory stimulation, environmental enrichment interventions help mitigate the negative effects of captivity and enhance the overall quality of life for laboratory animals. Moving forward, continued research and implementation of evidence-based enrichment strategies are essential to ensure the ethical and humane treatment of laboratory animals and to improve the reliability and validity of scientific research outcomes.

5.2 Recommendations

The study's findings provide valuable insights into the underlying mechanisms through which environmental enrichment influences stress and welfare in laboratory animals. By elucidating the relationship between environmental stimuli and behavioral, physiological, and cognitive outcomes, the study contributes to the theoretical understanding of how the physical and social environment shapes animals' well-being. Specifically, the study adds to existing theories such as the Biophilia Hypothesis, Optimal Stimulation Theory, and Stress Inoculation Theory by demonstrating their applicability in the context of laboratory animal welfare. These theoretical frameworks offer conceptual lenses through which researchers can interpret the complex interactions between environmental factors and animal welfare outcomes, enhancing our understanding of the underlying processes involved.

The study's recommendations have practical implications for laboratory animal care and management. Based on the findings, researchers and animal care professionals can implement evidence-based environmental enrichment programs to improve the welfare of laboratory animals. Practical recommendations may include enriching animals' living environments with features such as climbing structures, nesting materials, socialization opportunities, and cognitive challenges. Moreover, the study underscores the importance of individualized enrichment strategies tailored to the specific needs and preferences of different animal species and individuals. By incorporating environmental enrichment into routine animal care practices, laboratories can promote the well-being of their animal populations and enhance research quality and reproducibility.

The study's recommendations also inform the development of policies and guidelines aimed at promoting laboratory animal welfare. Policy-makers and regulatory bodies can use the study's findings to establish standards for environmental enrichment in laboratory animal facilities. For instance, guidelines may stipulate minimum enrichment requirements for different species and research contexts, as well as criteria for assessing the effectiveness of enrichment interventions. Additionally, the study highlights the importance of ongoing monitoring and evaluation of enrichment programs to ensure their efficacy and compliance with welfare standards. By integrating evidence-based recommendations into legislation and accreditation standards, policymakers can enhance the protection and well-being of laboratory animals across institutional and national levels.

In summary, the study on the effects of environmental enrichment on stress and welfare in laboratory animals makes valuable contributions to theory, practice, and policy in the field of laboratory animal welfare. By advancing our theoretical understanding of the mechanisms underlying environmental enrichment effects, providing practical recommendations for enrichment implementation, and informing policy development, the study enhances efforts to promote the welfare of laboratory animals and aligns research practices with ethical and scientific principles.

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