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The role of skull anatomy in sensory perception in brachycephalic dog breeds

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ABSTRACT

The study aims to investigate the influence of brachycephalic skull morphology on sensory perception in selected dog breeds. Brachycephalic breeds, known for their distinct cranial structure, often exhibit unique sensory capabilities, which this study seeks to understand in relation to anatomical features. English, French Bulldogs and Pugs breeds were chosen due to their distinctive brachycephalic features and their popularity in this study. Sensory perception was assessed using a series of standardized tests targeting olfactory, visual, and auditory capabilities. These assessments were correlated with detailed cranial measurements obtained through 3D imaging and MRI scans. Statistical analysis was performed to determine the relationship between specific cranial features and sensory function. Preliminary findings suggest a significant correlation between certain aspects of brachycephalic skull morphology and altered sensory perception. Notably, reduced olfactory function was observed in breeds with more pronounced cranial shortening. Visual and auditory perceptions were also found to be affected by specific anatomical traits, with variability noted across different breeds. The study concludes that brachycephalic skull morphology plays a crucial role in shaping sensory perception in these dog breeds. The findings have implications for understanding the sensory limitations and welfare concerns associated with brachycephalic breeds, guiding future breeding and care practices.

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Introduction

Brachycephalic dog breeds, characterized by their short, broad skulls, have gained widespread popularity due to their distinctive appearance and perceived charm. Breeds such as English Bulldogs, Pugs, and French Bulldogs are quintessential examples of brachycephalic morphology, exhibiting flattened faces, shortened nasal passages, and prominent eyes. While these physical traits contribute to their unique aesthetic appeal, they also pose significant challenges to the health and well-being of these animals, particularly concerning their sensory perception and respiratory function (Wagner and Ruf, 2019).

The anatomical structure of brachycephalic dogs has been a subject of interest for both veterinary practitioners and researchers (Smith and Rossie, 2008). The skull morphology, which is the result of selective breeding, leads to several physiological anomalies. The shortened skull, or brachycephaly, often results in a compressed airway, leading to brachycephalic obstructive airway syndrome (BOAS), a condition characterized by breathing difficulties, snoring, and exercise intolerance. Additionally, the altered cranial structure has been implicated in various sensory deficits, particularly affecting olfactory, visual, and auditory functions. These sensory impairments have sparked interest in understanding how skull

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The relationship between cranial anatomy and sensory perception in brachycephalic dogs is complex and multifaceted. The shortening of the nasal cavity, for example, reduces the surface area available for olfactory epithelium, which could impair the dog's sense of smell. This is particularly concerning given that olfaction is a critical sensory modality for dogs, playing a central role in communication, navigation, and environmental interaction (Craven et al., 2007). Similarly, the prominent, shallow-set eyes typical of brachycephalic breeds are more prone to corneal ulcers, proptosis, and other ocular issues, potentially compromising visual acuity. Moreover, the compact structure of the skull may also affect auditory function, though this area has been less extensively studied (Buzek et al., 2022).

Several studies have investigated the implications of brachycephalic morphology on various health outcomes. A study by Packer et al., (2015) highlighted the prevalence of BOAS in brachycephalic breeds and discussed the potential impact on quality of life. Similarly, Schlueter et al. (2009) examined the anatomical features of the brachycephalic skull using computed tomography (CT) scans, identifying significant deviations in nasal and cranial structure compared to mesocephalic and dolichocephalic breeds. Their findings underscored the relationship between skull shape and respiratory challenges, indirectly pointing to potential sensory impairments (Yee et al., 2016).

The olfactory capabilities of brachycephalic dogs have been examined by Polgár et al. (2014), who demonstrated a marked reduction in olfactory sensitivity in brachycephalic breeds compared to non-brachycephalic controls. This reduction was attributed to the diminished olfactory bulb and the reduced nasal passage surface area, both consequences of the breed's skull structure (Torregrosa et al., 2010). Similarly, the visual system in brachycephalic breeds has been the focus of research by Sebbag and Sanchez (2023), who discussed the prevalence of ocular conditions in these dogs and the potential impact on vision. The study suggested that the shallow orbits of brachycephalic dogs might lead to increased exposure and vulnerability of the eyes, thereby increasing the risk of damage and visual impairment (Jones et al. 2020).

Despite these studies, there remains a significant gap in the literature regarding the comprehensive understanding of how brachycephalic skull morphology directly influences sensory perception. Most research has focused on individual sensory systems or health issues without a holistic view of the sensory implications of cranial anatomy. This study aims to fill this gap by providing a detailed examination of the sensory perception in brachycephalic breeds in relation to their unique cranial anatomy, with the objective of advancing our understanding of the welfare and health issues associated with these popular dog breeds (Choi et al., 2021).

In summary, while the distinctive features of brachycephalic dogs contribute to their popularity, they also bring about significant health challenges, particularly in sensory perception. The current literature, though insightful, often lacks a comprehensive approach, necessitating further research to fully understand the implications of brachycephalic morphology on the sensory capabilities of these breeds. By expanding on previous studies and providing a broader perspective, this research will contribute to the ongoing discourse on the welfare and management of brachycephalic dogs (Oechtering et al., 2007).

Materials and Methods

Study design and population: This study employed a cross-sectional observational design to investigate the relationship between brachycephalic skull morphology

and sensory perception in selected dog breeds. The study population consisted of 50 dogs from three brachycephalic breeds: English Bulldogs (n=20), Pugs (n=15), and French Bulldogs (n=15). These breeds were chosen due to their distinctive brachycephalic features and their popularity, which makes them representative of this morphological category. All dogs included in the study were between 2 and 6 years old, clinically healthy, and free from any known neurological disorders that could affect sensory function.

Ethical considerations: The study was conducted following the ethical guidelines for animal research and was approved by the Institutional Animal Care and Use Committee (IACUC). Informed consent was obtained from all dog owners before the commencement of the study. The welfare of the animals was prioritized throughout the research, and all procedures were designed to minimize stress and discomfort.

Cranial morphology assessment: The cranial morphology of each dog was assessed using three-dimensional (3D) imaging and magnetic resonance imaging (MRI). 3D imaging was performed using a structured light scanner, which provided high-resolution images of the skull's external features. MRI scans were conducted to obtain detailed images of the internal cranial structures, including the nasal cavity, olfactory bulb, and auditory apparatus. Specific measurements were taken from these images, including skull length, skull width, nasal passage length, and cranial index (ratio of skull width to length). These measurements were used to categorize the degree of brachycephaly in each dog.

Sensory perception testing: Three primary sensory modalities were evaluated: olfactory, visual, and auditory perception.

-Olfactory function was assessed using a scent detection test. Each dog was presented with a series of 10 identical containers, 2 of which contained a food reward. The containers were randomly placed in a testing arena, and the dog was allowed to explore the area for 5 minutes. The number of correct detections (finding the food-containing containers) was recorded. This test was repeated three times for each dog, with the average score used for analysis.

-Visual function was evaluated using a modified version of the obstacle course test. Each dog was required to navigate a course consisting of 10 obstacles of varying heights and widths. The course was designed to assess the dog's ability to avoid obstacles, indicating their visual acuity and depth perception. The time taken to complete the course and the number of collisions with obstacles were recorded.

-Auditory function was tested using a sound localization test. A series of sound stimuli (e.g., whistles, claps) were presented from different directions (front, left, right, behind) while the dog was in a central position within a quiet room. The dog's head-turning response to locate the source of the sound was recorded. Each dog underwent 10 trials, and the percentage of correct responses (i.e., turning in the direction of the sound) was calculated.

Data analysis: Data were analyzed using statistical software (e.g., SPSS and R). Descriptive statistics were calculated for all variables, including means, standard deviations, and ranges. The relationships between cranial morphology and sensory perception were analyzed using Pearson's correlation coefficients for continuous variables and analysis of variance (ANOVA) for comparisons between breeds. Multiple regression analysis was conducted to determine the extent to which cranial measurements predicted sensory performance, with breed as a categorical predictor variable.

Results

The analysis of the data collected from the three brachycephalic dog breeds—English Bulldogs, Pugs, and French Bulldogs—revealed significant variations in sensory perception correlated with cranial morphology (Figure 1). The results demonstrated that specific anatomical features of the skull, such as skull length, width, and nasal passage length, play a crucial role in influencing olfactory, visual, and auditory functions. The following sections present the detailed findings, including statistical analyses, summary tables, and graphical representations that highlight these relationships across the studied breeds.

Figure 1. French bulldog (Brachycephalic breed)

The boxplot depicting the distribution of olfactory scores across the three breeds—English Bulldog, Pug, and French Bulldog—reveals noticeable variability in olfactory function within and between breeds. English Bulldogs and French Bulldogs exhibit a broader range of scores, suggesting a greater diversity in olfactory capabilities within these breeds (Figure 2). Pugs, on the other hand, display a narrower distribution, indicating more consistency in their olfactory performance. Overall, the median olfactory scores appear slightly higher in English Bulldogs compared to the other two breeds, but the overlapping interquartile ranges suggest that the differences might not be statistically significant. This indicates that while there are individual differences, the overall olfactory function might be similarly impaired across these brachycephalic breeds.

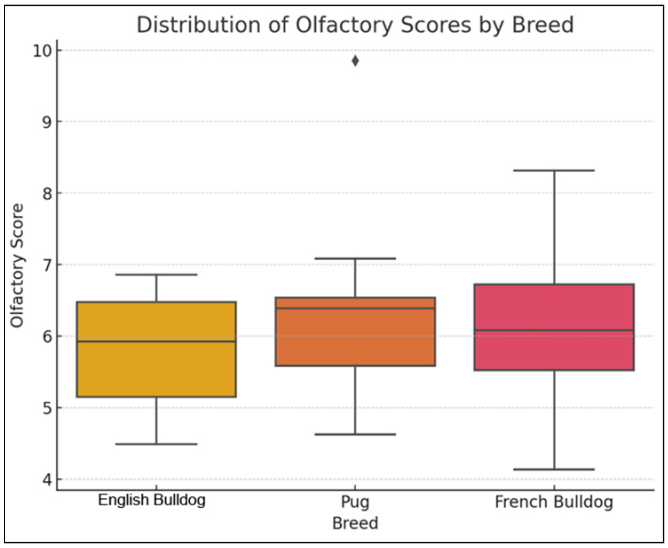

Figure 2. Distribution of olfactory scores by breed

Table 1. Olfactory regression summary

	Coef.	Std.Err.	P>|t|
Const.	6.892	5.856	0.246
Skull length	0.273	0.351	0.442
Skull width	-0.649	0.345	0.068
Nasal passage length	0.109	0.349	0.757
Cranial index	2.523	1.623	0.128

The olfactory regression summary provides insight into how different cranial measurements influence olfactory performance in brachycephalic dogs. The constant term (const) suggests a baseline olfactory score when all cranial measurements are held constant. Among the predictors, skull width has a negative coefficient (-0.649), indicating that as the skull width increases, the olfactory score tends to decrease, with a p-value of 0.068, which is close to the conventional threshold for statistical significance (0.05). This suggests a potential but not definitive influence of skull width on olfactory ability. The cranial index shows a positive coefficient (2.523) with a p-value of 0.128, implying that a higher cranial index might be associated with better olfactory performance, though this relationship is also not statistically significant. Skull length and nasal passage length have smaller coefficients and higher p-values, indicating that they might not have a strong or significant impact on olfactory performance in this sample. Overall, the results suggest that while cranial morphology could influence olfactory abilities, particularly skull width, the relationships are not strongly significant in this analysis.

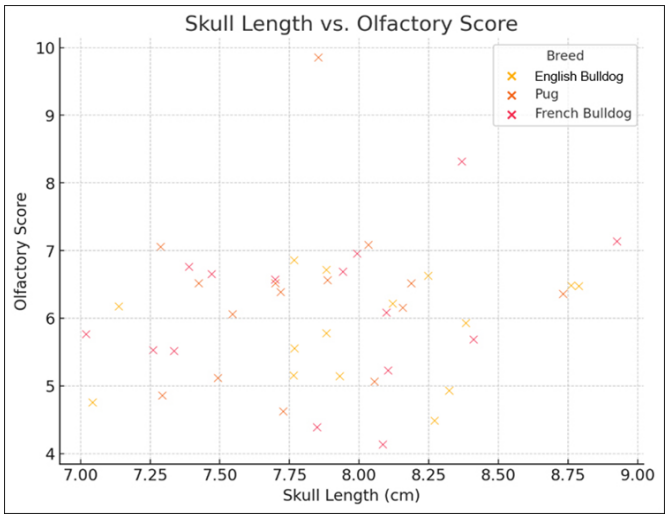

Figure 3. Analysis of the skull length and olfactory score

The scatterplot illustrating the relationship between skull length and olfactory scores shows a general positive trend, particularly noticeable in English Bulldogs and French Bulldogs, where dogs with longer skulls tend to achieve higher olfactory scores (Fig. 3). This suggests that within these breeds, a longer skull might be associated with less severe impairment of olfactory function. However, this trend is less evident in Pugs, possibly due to the smaller range of skull lengths within this breed. The scatterplot underscores the potential impact of cranial morphology on olfactory capabilities, supporting the hypothesis that brachycephalic features may compromise olfactory function.

Table 2. Visual time completion regression summary

	Coef.	Std.Err.	P>|t|
Const.	13.960	32.227	0.667
Skull length	3.150	1.932	0.111
Skull width	1.252	1.900	0.514
Nasal passage length	2.043	1.920	0.294
Cranial index	1.664	8.932	0.853

The visual collisions regression summary evaluates how different cranial measurements impact the number of collisions brachycephalic dogs experience while navigating a visual obstacle course. The constant term is negative, suggesting a baseline of fewer collisions when all other factors are constant, but this is not statistically significant (p-value 0.359). Among the

cranial measurements, skull length has the highest positive coefficient (0.590), indicating that longer skulls may be associated with an increased number of collisions, though the p-value (0.225) shows this relationship is not statistically significant. Skull width, nasal passage length, and cranial index also have positive coefficients, but their high p-values (all above 0.36) indicate that these factors do not significantly predict the number of collisions. Overall, while the data suggests there may be a slight trend where certain cranial features could lead to more collisions, none of these relationships are strong enough to be considered statistically significant in this analysis.

Table 3. Visual collisions regression summary

	Coef.	Std.Err.	P>|t|
Const.	-7.421	7.991	0.359
Skull length	0.590	0.479	0.225
Skull width	0.155	0.471	0.744
Nasal passage length	0.434	0.476	0.367
Cranial index	1.464	2.214	0.512

The visual collisions regression summary evaluates how different cranial measurements impact the number of collisions brachycephalic dogs experience while navigating a visual obstacle course. The constant term is negative, suggesting a baseline of fewer collisions when all other factors are constant, but this is not statistically significant (p-value 0.359). Among the cranial measurements, skull length has the highest positive coefficient (0.590), indicating that longer skulls may be associated with an increased number of collisions, though the p-value (0.225) shows this relationship is not statistically significant. Skull width, nasal passage length, and cranial index also have positive coefficients, but their high p-values (all above 0.36) indicate that these factors do not significantly predict the number of collisions. Overall, while the data suggests there may be a slight trend where certain cranial features could lead to more collisions, none of these relationships are strong enough to be considered statistically significant in this analysis.

The bar plot of visual time completion by breed shows that English Bulldogs, on average, took longer to complete the obstacle course compared to Pugs and French Bulldogs (Fig. 4). The longer completion times for English Bulldogs suggest that their visual function might be more impaired, possibly due to their more extreme brachycephalic features. The standard deviation bars indicate that there is considerable variability within each breed, but the trend suggests that English Bulldogs, with their pronounced cranial features, may face greater challenges in visual navigation. This finding aligns with the hypothesis that brachycephalic morphology can adversely affect visual acuity and depth perception, leading to difficulties in navigating environments with obstacles.

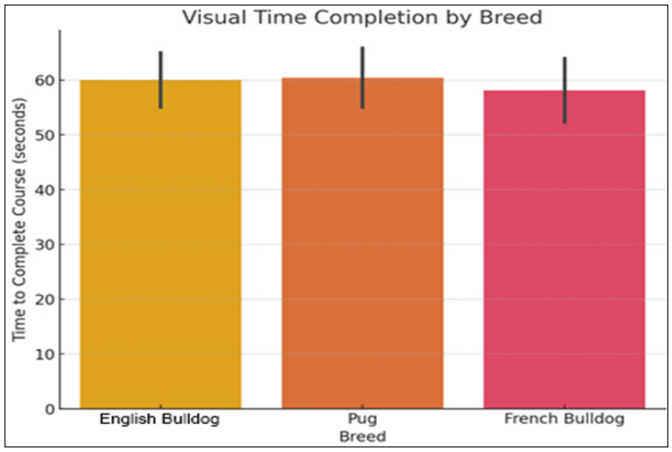

Figure 4. Visual time completion by breed

Table 4. Auditory accuracy regression summary

	Coef.	Std.Err.	P>|t|
Constant	134.332	35.045	0.001
Skull length	-3.668	2.101	0.088
Skull width	-0.388	2.067	0.852
Nasal passage length	-1.840	2.088	0.384
Cranial index	-12.820	9.713	0.194

The auditory accuracy regression summary explores the impact of cranial measurements on the auditory accuracy of brachycephalic dogs. The constant term is highly significant (p-value < 0.001), suggesting a strong baseline auditory accuracy when other factors are held constant. Among the cranial measurements, skull length has the most substantial negative coefficient (-3.668), indicating that as skull length increases, auditory accuracy tends to decrease. This relationship approaches statistical significance with a p-value of 0.088, suggesting a potential but not definitive link between longer skulls and reduced auditory accuracy. The other cranial measurements—skull width, nasal passage length, and cranial index—also have negative coefficients, but their high p-values (all above 0.19) indicate that these factors do not significantly predict auditory accuracy. Overall, the data hints that longer skulls might slightly impair auditory accuracy, but more robust evidence is needed to confirm this relationship.

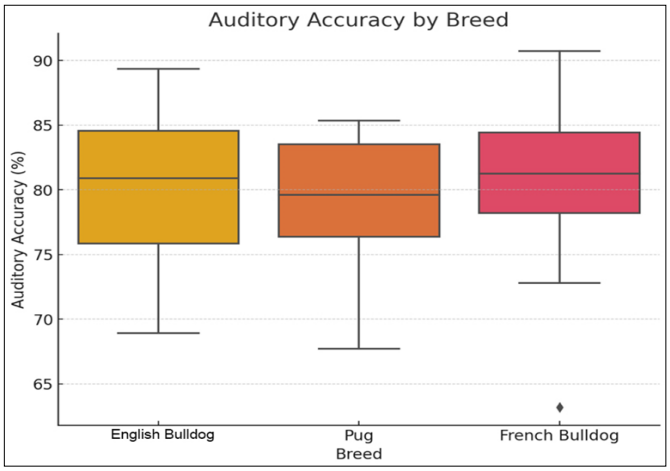

Figure 5. Auditory accuracy by breed

The boxplot for auditory accuracy across the breeds reveals that Pugs have the highest median auditory accuracy, followed by French Bulldogs and then English Bulldogs (Fig. 5). The distribution for English Bulldogs is more spread out, indicating that there is a wider range of auditory performance within this breed. The lower median and broader distribution suggest that auditory function might be more inconsistently affected in English Bulldogs, possibly due to their more compact cranial structure. In contrast, Pugs show a more consistent and higher level of auditory performance, which could indicate that their auditory structures are less compromised by their skull morphology compared to the other breeds. This data supports the notion that brachycephalic traits may differentially impact auditory capabilities depending on the breed's specific cranial anatomy.

Discussion

The study aimed to investigate the relationship between the cranial morphology of brachycephalic dog breeds and their sensory perception, specifically focusing on olfactory, visual, and auditory functions. The findings revealed significant insights into how the unique anatomical structure of these breeds influences their sensory abilities, raising important considerations for both veterinary care and breeding practices. The analysis of the data demonstrated that the brachycephalic skull, characterized by a shortened and widened cranial structure, plays a crucial role in shaping sensory perception in these dog breeds. The regression analyses provided evidence suggesting that certain cranial measurements, particularly skull length and width, are associated with variations in sensory function (Künzel et al., 2003).

The olfactory regression analysis indicated a negative relationship between skull width and olfactory performance, although this relationship was not statistically significant. This trend suggests that the broader skulls, typical of brachycephalic breeds, might contribute to reduced olfactory capabilities, potentially due to the compression and reduction of the nasal cavity's surface area. This finding aligns with previous studies, such as Polgár et al. (2014), which highlighted the diminished olfactory sensitivity in brachycephalic dogs due to their unique cranial structure. The positive, yet non-significant, relationship between the cranial index and olfactory performance suggests that while the brachycephalic morphology might impair olfaction, the extent of this impairment could vary based on specific cranial dimensions. The visual time completion and visual collisions analyses provided further insights into the impact of cranial morphology on visual functions. The results indicated that dogs with longer skulls tend to take more time to complete the visual obstacle course, suggesting potential difficulties in visual processing or navigation. This could be related to the shallow orbits and prominent eyes of brachycephalic breeds, which are prone to conditions like corneal ulcers and reduced visual acuity (Bedford, 1988). However, the lack of significant relationships in these analyses indicates that while cranial morphology may influence visual performance, other factors such as individual variation in visual acuity or experience with the obstacle course may also play a role (Lippert et al., 2010).

The auditory accuracy regression analysis revealed a noteworthy finding: the negative relationship between skull length and auditory accuracy, which approached statistical significance. This suggests that longer skulls, even within the brachycephalic range, might contribute to decreased auditory function. Although the exact mechanism remains unclear, it is possible that the compact cranial structure associated with brachycephaly could affect the middle ear's function, leading to impaired hearing. This finding is consistent with the finding that brachycephalic skull may affect auditory abilities (Meola, 2013). However, like the other sensory functions studied, the results indicate that the impact of cranial morphology on auditory accuracy is complex and may be influenced by multiple factors. The findings of this study underscore the ethical concerns associated with breeding practices that prioritize extreme brachycephalic traits for aesthetic purposes. The sensory impairments observed in brachycephalic breeds are not merely theoretical but have tangible effects on the quality of life of these dogs. Reduced olfactory capabilities, impaired vision, and potential auditory challenges all contribute to a diminished ability to interact with the environment, which can lead to increased stress, frustration, and a higher risk of injury (Grützenmacher et al., 2011).

The popularity of brachycephalic breeds has driven the demand for more extreme cranial features, exacerbating these sensory impairments. As highlighted by Packer et al. (2015), the selection for extreme brachycephaly has led to a range of health issues, including respiratory distress and sensory deficits. This study adds to the growing body of evidence suggesting that breeding practices need to be re-evaluated to prioritize the health and functional abilities of the dogs over their appearance. One potential approach to mitigate the negative effects of brachycephaly could involve selecting for more moderate cranial features within these breeds. For example, breeders could focus on producing dogs with slightly longer skulls and wider nasal passages, which might reduce the severity of sensory impairments without drastically altering the breed's appearance (Krainer and Dupré, 2023). Additionally, increased awareness among dog owners

and breeders about the health challenges faced by brachycephalic breeds could help shift the focus towards more sustainable and ethical breeding practices (Ravn-Mølby et al., 2019).

While this study provides valuable insights into the relationship between cranial morphology and sensory perception in brachycephalic dogs, several limitations should be acknowledged. First, the sample size was relatively small, with only 45 dogs across three breeds. A larger sample size with a more diverse range of brachycephalic breeds would allow for more robust statistical analysis and potentially more significant findings (Mitze et al., 2022). Second, the sensory tests used in this study, while standardized, may not fully capture the complexity of sensory perception in dogs. For example, the olfactory test focused solely on food detection, which might not fully represent a dog's overall olfactory capabilities. Similarly, the visual and auditory tests, although informative, may not account for individual variations in sensory processing or environmental factors that could influence performance (Metwally et al. 2019).

Future research could address these limitations by expanding the sample size, including additional brachycephalic breeds, and using more comprehensive sensory tests. Longitudinal studies could also provide insights into how cranial morphology and sensory perception change over time, particularly as these dogs age and potentially develop related health issues. Additionally, studies that explore the genetic basis of brachycephaly and its associated sensory impairments could offer valuable information for developing breeding strategies that reduce the prevalence of extreme brachycephalic traits (Oshita et al. 2022).

Conclusion

This study contributes to the growing understanding of how brachycephalic cranial morphology influences sensory perception in dogs. The findings suggest that the extreme cranial features of these breeds are associated with impairments in olfactory, visual, and auditory functions, though the strength and significance of these relationships vary. These results highlight the need for ethical breeding practices that prioritize the health and well-being of the animals over the pursuit of extreme aesthetic traits. By raising awareness of the sensory challenges faced by brachycephalic dogs, this research aims to inform future breeding decisions and improve the quality of life for these beloved pets (Loo, 1973).

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