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The Impacts of a Commercial Bubble Curtain on Zoo-Housed African Penguin (*Spheniscus demersus*) Swimming Behavior

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Abstract: Swimming is an important behavior for all penguin species. However, zoo-housed penguins typically do not swim as often as their wild counterparts, which may have consequences for their health and welfare. In an effort to increase the swimming time of the African penguin (*Spheniscus demersus*) population at Lincoln Park Zoo in Chicago, IL, USA (21 adults: 13 males, 8 females), we introduced a commercially available bubble curtain to the outdoor pool within the penguins' habitat. The bubble curtain pushes pressurized air out through a hose fitted with small holes to create a stream of bubbles that generate water movement, which could entice penguins to swim. Over the course of 2 months, the penguins were exposed to a series of alternating conditions characterized by the bubble curtain being off or on for 2-week periods. A total of 228 swimming bouts were observed during this study. The bubble curtain did not increase the amount of time the penguins spent swimming, nor the maximum number of penguins in the pool during swim bouts. Rather, the penguins spent more time swimming when the bubble curtain was turned off, and the number of penguins in the pool during swim bouts was consistent across experimental phases. Additionally, we found that penguins swam the most when air temperatures were between 31 and 40 °F (approximately −1 to −4 °C). Unexpectedly, at least three individual penguins swam overnight between the hours of midnight and 6:00, highlighting the value of monitoring animals during entire 24 h periods. Collectively, this study provides detailed information about the swimming behavior of a zoo-housed African penguin population, and indicates that a bubble curtain was ineffective at stimulating swimming.

Keywords: penguin; swimming; zoo(s); temperature; animal welfare

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1. Introduction

Swimming is an important behavior for all penguin species, both in wild and zoo-housed populations. In the wild, penguins can spend several hours per day swimming in search of food, often in turbulent ocean waters [1–4]. Contrary to their wild counterparts, zoo-housed penguins are typically hand-fed [5–7] so that animal care staff can easily monitor the health and nutrition of each individual penguin, and it may be that hand-feeding causes penguins to lose the motivation to swim. At least one study has demonstrated that zoo-housed penguins spend more time standing than swimming [8]. Other studies have noted that increased time spent standing is associated with bumblefoot in zoo-housed penguins [9,10], which can be detrimental to penguin health and welfare. Bumblefoot, or pododermatitis, is a condition of widespread concern for penguins in human care. Clinical bumblefoot is characterized by the inflammation and infection of plantar lesions that emerge due to excessive pressure on the plantar surface of the avian foot [10].

Efforts to increase the amount of time that penguins spend swimming can be a strategy to increase naturalistic behavior patterns and mitigate instances of bumblefoot in zoo-housed penguin populations. Notably, preventing bumblefoot has been cited as a motivation behind multiple studies on penguin swimming behavior [5,6,11,12]. Food has

often been utilized to attract penguins to the water in attempts to increase swimming time in zoo-housed penguin populations. For example, one study [11] trained penguins to use underwater enrichment devices filled with fish. Similarly, another study [5] used live fish feeding to attract penguins to the water. While both studies were effective at increasing swimming time, the increased swimming time was limited to the feeding events themselves. Therefore, food-based methods may not be an effective long-term solution to increase penguin swimming time. Finding a solution to increase swimming time outside of short-term feeding events will be necessary to mitigate the risk of bumblefoot and increase naturalistic behaviors in zoo-housed penguin populations. At least one study has demonstrated a link between penguin swimming activity and rain [13], indicating that water movement may be effective at enticing penguins to swim.

We introduced a commercially available bubble curtain to the outdoor pool within the African penguin (*Spheniscus demersus*) habitat at Lincoln Park Zoo (Chicago, IL, USA) in an effort to increase the penguins' swimming time. The bubble curtain pushes pressurized air out through a hose fitted with small holes to create a stream of bubbles. We hypothesized that the water movement generated by the bubble curtain would influence the swimming behavior of the penguins. Specifically, we predicted that the total amount of time the penguins spent swimming and the maximum number of penguins in the pool during swim bouts would increase during the periods when the bubble curtain was turned on relative to the periods in which the bubble curtain was turned off.

2. Materials and Methods

2.1. Subjects and Habitat

The population of African penguins (*Spheniscus demersus*) at Lincoln Park Zoo consists of 21 adults (13 males, 8 females); all are captive-born. The average age of the penguins was 9 years old, and ranged from 3–18 years. At the time of this study, all penguins were healthy and had no known health issues that may have potentially limited their ability to swim. The outdoor exhibit where the penguins were observed consisted of a 331.23 square meter area including a 77,600 L pool (for additional details about the habitat, see [14]). Except for rare cases of pool/habitat maintenance, the penguins had access to this outdoor pool 24 h per day, 7 days per week. The penguins had uninterrupted access to the pool during the course of this study.

2.2. Study Design

A commercially available bubble curtain (Diversified Pond Supplies; Wapakoneta, OH, USA) was installed in the bottom of the penguin pool on 15 November 2022. Data collection began the following day and lasted approximately 2 months, during which time the penguins were exposed to a series of alternating conditions characterized by the bubble curtain being off or on for 2-week periods. After installation, the bubble curtain remained off for the first ~2 weeks of data collection to allow the penguins time to acclimate to the presence of the bubble curtain in the pool, and to collect data on the penguins' swimming activity while the bubble curtain was present but off. In the subsequent ~2-week period, the bubble curtain was turned on between the hours of approximately 07:00–15:00 each day. The ~2-weeks off and ~2-weeks on bubble curtain procedure was replicated the following month. The duration of each experimental phase (Phase 1: bubble curtain off, Phase 2: bubble curtain on, Phase 3: bubble curtain off, Phase 4: bubble curtain on) varied slightly due to brief periods of weather-related technical difficulties. For the exact days per condition, see Table 1.

Table 1. Duration of each experimental phase. The bubble curtain was installed on 15 November 2022.

Phase	Bubble Curtain Condition	Duration	Dates
Phase 1: Week 1–2	off all hours	15 days	16 November–30 November
Phase 2: Week 3–4	on 7:00–15:00	14 days	1 December–14 December
Phase 3: Week 5–6	off all hours	19 days	15 December–2 January
Phase 4: Week 7–8	on 7:00–15:00	15 days	3 January–17 January

2.3. Behavioral Data Collection

A commercially available video camera (Wyze Cam v3; Wyze Labs; Seattle, WA, USA) with a 256 GB microSD card was installed above the penguin pool on the same day that the bubble curtain was installed to allow for remote monitoring of the penguins' swimming activity during the entire 24 h period. The camera placement was chosen based on the ability to see the pool surface as well as the proximity to an electrical outlet. Data on the penguins' swimming activity were collected during the first 72 h of each week for a total of 8 72 h collection periods (1 per each week of the study; 2 per each experimental phase; 576 total hours of observation). The first 72 h was selected in order to thoroughly characterize their initial response and accommodate for changes in the duration of exposure to each condition due to logistical constraints. For the weeks in which the bubble curtain was turned on, the time that the bubble curtain was first turned on counted as the start of the 72 h period for that week. Video recordings were reviewed by a single, trained observer who screened footage in 2 min intervals for each 72 h data collection period. During the video screening, the observer scanned through each 2 min interval until a penguin was sighted. Once a penguin was sighted in the pool, the observer rewound the video to find the exact moment that the penguin entered the pool, and then the swimming bout was observed in its entirety. Swim bouts were defined as any instance when at least one penguin was in the pool. Swim bouts ended when no penguins remained in the pool for a period of at least 1 min. Due to the positioning of the video camera above the pool (Supplementary Materials File S1), there were a few instances in which it was not possible to observe a penguin exiting the pool. In these cases, if a penguin was out of sight for >2 min, then the last time the penguin was sighted counted as the end of that swimming bout.

For each 72 h period, data from every swim bout was recorded, including: the time penguin(s) entered the pool, the time penguin(s) exited the pool, swim bout duration, the minimum number of penguins in the pool during the swim bout, and the maximum number of penguins in the pool during the swim bout. The color-coded armbands used to identify individual penguins were not distinguishable from the video camera footage; therefore, penguin IDs were not included in the data collection. Data on the air temperature and pool temperature were also recorded, as these factors could influence the penguins' swimming activity. The air temperature data were collected retroactively from the Chicago Midway Airport Weather Station (located 10 mi southwest of Lincoln Park Zoo) via timeanddate.com for each time point during which a swimming bout was observed. The pool temperature data were collected retroactively from institutional animal care logs available via Tracks® in which the pool temperatures were recorded once per day.

2.4. Data Analysis

Statistical analyses were performed in R version 4.2.1 [15]. The data were tested for normality using a Shapiro–Wilk test, and parametric or non-parametric tests were used as appropriate. A Durbin–Watson test was used to determine if air temperature and pool temperature were autocorrelated using the 'lmtest' package [16]. Generalized linear models with a Poisson distribution were used to examine how the bubble curtain impacted variation in swimming time and the maximum number of penguins in the pool during swimming bouts using the 'lme4' package [17]. Separate models were constructed for each of the response variables (swimming time and the maximum number of penguins in the pool). These models included the following predictor terms as fixed effects: bubble

curtain (on/off), air temperature (°F) and pool temperature (°F). Reduced models were also included for comparison. The best-fit model was identified using the Akaike information criterion (AIC).

To provide additional context regarding the penguins' overall swimming behavior, a Kolmogorov–Smirnov test was used to determine how the number of swimming bouts differed at each hour of the day between the two types of experimental phases (Phases 1 and 3 when the bubble curtain was off, versus Phases 2 and 4 when the bubble curtain was on). Additionally, given the lack of information on 24 h behavioral patterns in many species [18], including penguins, we considered how swimming changed across daytime hours, and the occurrences of overnight swimming were recorded daily throughout the entire experiment (i.e., not limited to the 72 h data collection periods previously described), including the number of penguins in the pool during overnight swim bouts and the duration of overnight swim bouts. Throughout, all means are reported ± SD. This study was approved by the Lincoln Park Research Committee, the governing body that oversees all research conducted at the institution. Data are available upon request.

3. Results

A total of 228 swimming bouts were observed during this study. The minimum number of penguins in the pool during a swim bout was one, and the maximum number of penguins in the pool during a swim bout was ten (mean = 2.24 ± 1.71 penguins; mode = 1 penguin). Table 2 details the average swim bout duration, the count of swim bouts, total time swimming, average air temperature, and average pool temperature for each experimental phase. Air temperature varied significantly between experimental phases (Kruskal–Wallis, $X^2 = 82.49$, df = 44, $p < 0.01$). Pool temperature also varied significantly between experimental phases (Kruskal–Wallis, $X^2 = 85.42$, df = 8, $p < 0.01$). However, the pool temperature ranged from 46–60 °F (approximately 8–15 °C), which aligns with the water temperatures naturally experienced by this species. Air temperature and pool temperature were autocorrelated (Durbin–Watson, DW = 0.21, $p < 0.01$), and therefore these variables were included separately in subsequent models.

Table 2. The average swim bout duration ± SD, count swim bouts, total time swimming, average air temperature ± SD (°F), and average pool temperature ± SD (°F) for each experimental phase of the study.

Phase	Bubble Curtain	Average Swim Bout Duration (minutes)	Count Swim Bouts	Total Time Swimming (minutes)	Average Air Temperature (°F)	Average Pool Temperature (°F)
Phase 1: Week 1–2	Off	5 ± 6	65	360	43 ± 9	51 ± 2
Phase 2: Week 3–4	On	12 ± 19	63	572	38 ± 6	54 ± 4
Phase 3: Week 5–6	Off	9 ± 16	42	414	23 ± 11	49 ± 4
Phase 4: Week 7–8	On	4 ± 5	58	260	37 ± 6	53 ± 6

3.1. Swimming Time

The amount of time the penguins spent swimming was best predicted by the model which included the bubble curtain and air temperature (AIC = 3048.76, df = 3). The bubble curtain ($p < 0.01$) and air temperature ($p < 0.01$) were both significant factors within this model (for a full model summary, see Supplementary Materials File S2). For a full list of models constructed, see Table 3. The amount of time the penguins spent swimming was highest during Phase 2 of the study, when the bubble curtain was first turned on, then declined over the course of the study (Table 2). The penguins spent more time swimming when air temperatures were between 31 and 40 °F (approximately −1 to −4 °C; Table 4).

Table 3. General linear models (GLM) constructed for each response variable (swimming time and maximum number of penguins in the pool). In all models, bubble curtain condition (on/off), air temperature, and pool temperature were included as fixed effects, and a Poisson distribution was applied. For comparison, simple models were constructed that included only the bubble curtain condition, air temperature, and pool temperature. Within the models, swimming time is listed as "Swimtime" and the maximum number of penguins in the pool is listed as "Max". Akaike information criterion (AIC) and degrees of freedom (df) are included for each model. The best-fitting model (based on AIC values) for each response variable is bolded.

Response Variable	Model	AIC	df
Swimming time	**GLM (Swimtime~Bubble curtain + AirTemp)**	**3048.76**	**3**
	GLM (Swimtime~Bubble curtain + PoolTemp)	3055.04	3
	GLM (SwimTime~Bubble curtain)	3059.01	2
	GLM (SwimTime~AirTemp)	3129.66	2
	GLM (SwimTime~PoolTemp)	3127.06	2
Maximum number of penguins in pool	GLM (Max~Bubble curtain + AirTemp)	821.36	3
	GLM (Max~Bubble curtain + PoolTemp)	823.55	3
	GLM (Max~Bubble curtain)	821.61	2
	GLM (Max~AirTemp)	**819.36**	**2**
	GLM (Max~PoolTemp)	821.58	2

Table 4. The count of swim bouts, total time penguins spent swimming, and average ± SD swim bout duration in relation to air temperature. Penguins had the most swim bouts and the greatest total time swimming when air temperatures were between 31 and 40 (°F).

Air Temperature (°F)	Count Swim Bouts	Total Time Swimming (minutes)	Average Swim Bout Duration (minutes)
−10–0	2	2	1 ± 0
1–10	5	26	5 ± 3
11–20	9	119	13 ± 19
21–30	45	397	9 ± 13
31–40	110	742	7 ± 15
41–50	35	226	7 ± 7
51–60	22	94	4 ± 6

3.2. Maximum Number of Penguins in the Pool

The maximum number of penguins in the pool was best predicted by the model that included only air temperature (AIC = 819.36, df = 2), even though air temperature ($p = 0.12$) was not significant in this model (for a full model summary, see Supplementary Materials File S2). Figure 1 illustrates that there was no relationship between the maximum number of penguins in the pool during swim bouts and air temperature across experimental phases. The average number of penguins in the pool during swim bouts was 2.42 ± 1.87 during Phase 1, 2.13 ± 1.57 during Phase 2, 2.14 ± 2.03 during Phase 3, and 2.24 ± 1.43 during Phase 4.

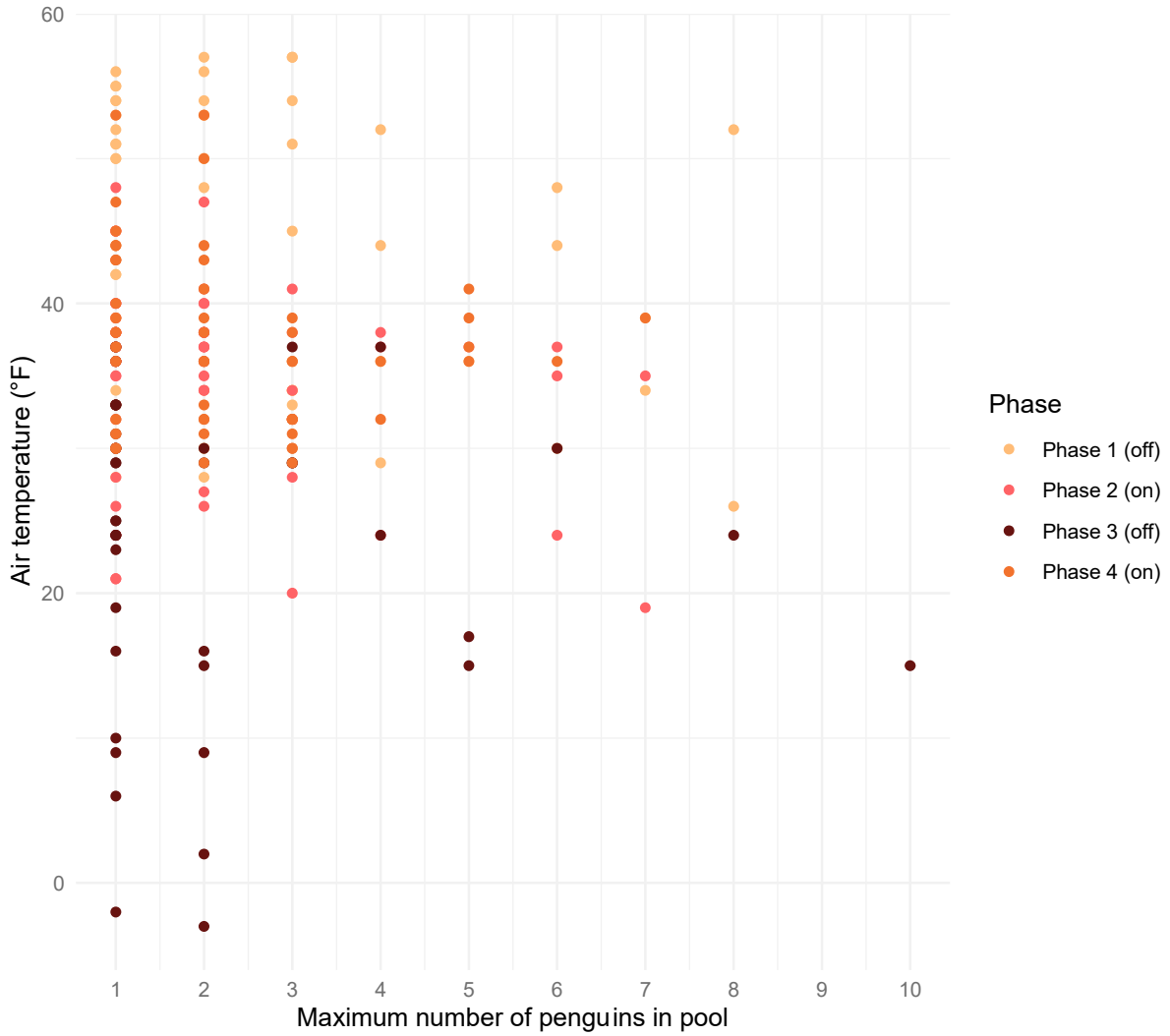

Figure 1. The maximum number of penguins in the pool in relation to air temperature (°F). Each dot represents a swimming bout and is colored to denote the experimental phase in which the swimming bout occurred. There was no relationship between the maximum number of penguins in the pool during swimming bouts in relation to air temperature across experimental phases.

3.3. Effect of Time of Day

The number of swimming bouts at each hour of the day did not differ significantly between the two types of experimental phases (Kolmogorov–Smirnov test, D = 0.125, p = 0.92). Figure 2 illustrates the number of swimming bouts at each hour of the day for each experimental phase. During Phase 2 of the study, when the amount of time spent swimming was highest, the penguins spent 276 min swimming during the hours of 7:00–15:00 when the bubble curtain was turned on, and 296 min swimming during the hours of 15:00–7:00 when the bubble curtain was turned off. During Phase 4 of the study, the other phase in which the bubble curtain was on, the penguins spent 196 min swimming during the hours of 7:00–15:00 when the bubble curtain was turned on, and 64 min swimming during the hours of 15:00–7:00 when the bubble curtain was turned off.

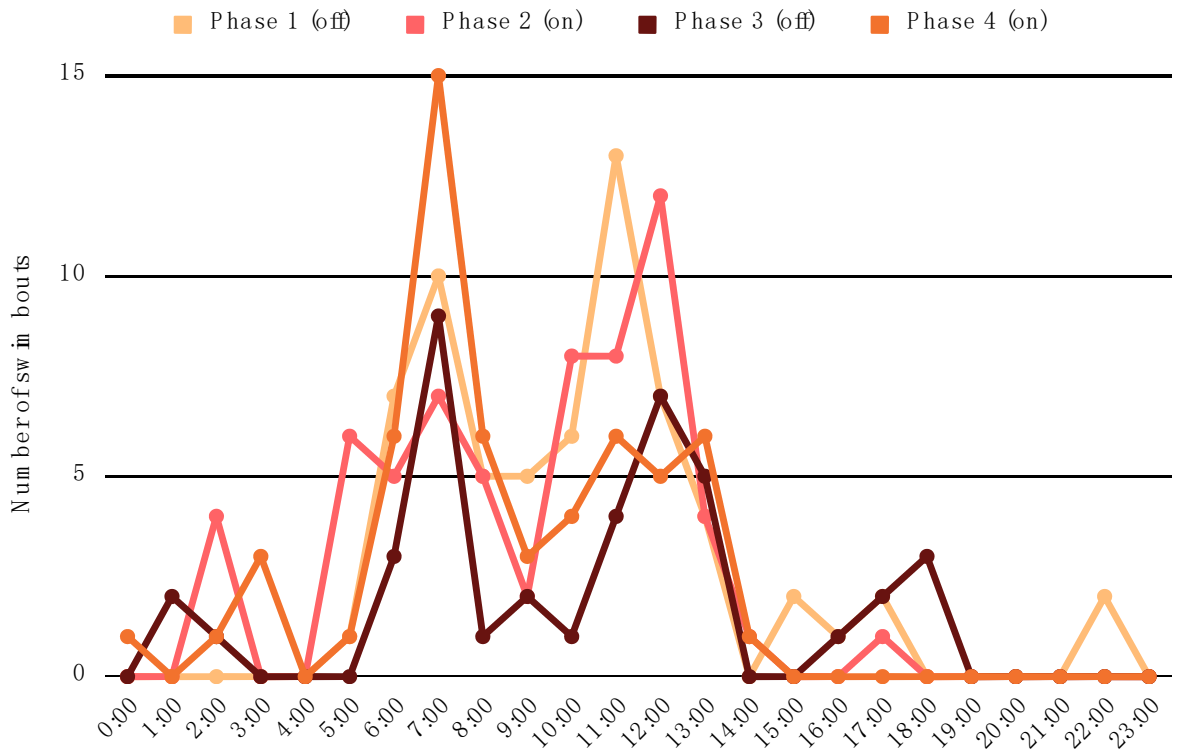

Figure 2. The number of swimming bouts (total count) across each hour of the day across experimental phases. Lines are colored to denote each experimental phase. The number of swimming bouts across each hour of the day were similar across experimental phases.

3.4. Nighttime Swimming

For the purposes of this study, we defined "overnight" as 0:00–6:00. A total of 28 overnight swim bouts were observed over the course of the study (Figure 2 shows swim bouts per 24 h). The minimum number of penguins in the pool during an overnight swim bout was one and the maximum was three. The average duration of an overnight swim bout was 40 ± 48 min; range minimum-maximum = 1–178 min. There were zero overnight swim bouts during Phase 1 of the study, twelve during Phase 2, ten during Phase 3, and six during Phase 4.

4. Discussion

We set out to determine whether the addition of a commercially available bubble curtain would impact swimming behavior in zoo-housed African penguins. We found that the bubble curtain and air temperature, collectively, best predicted the amount of time penguins spent swimming. There was an observed increase in the amount of time the penguins spent swimming during Phase 2 of the study, when the bubble curtain was first turned on. However, this observed increase in time spent swimming occurred outside of the timeframe when the bubble curtain was turned on. The amount of time the penguins spent swimming declined after this initial spike, which suggests a potential novelty and habituation effect to the bubble curtain [19,20]. Collectively, our results indicate that while there was an overall increase in time spent swimming during Phase 2, this increase was not driven by the water movement generated by the bubble curtain, as the penguins spent more time swimming during the hours when the bubble curtain was turned off.

Similarly, the bubble curtain did not increase the maximum number of penguins in the pool during swim bouts. Rather, the number of penguins in the pool during swim bouts was consistent across experimental phases. This may indicate that the outdoor pool of the penguin habitat is not conducive to high density swimming bouts. During the entire experiment, the highest density of penguins observed in the pool at a single time was

10 individuals; however, this was observed only once. Of the 228 swim bouts that were observed, the majority consisted of only 1–2 penguins. One study, which examined how enclosure features influence penguin behavior, found that pool size impacted swimming behavior [21]. Another study, which examined 16 institutions, found that larger pool sizes were correlated with hatching success in zoo-housed penguins [22]. Notably, some of the pools in these studies were larger compared to the pool in this study which is 77,600 L. Collectively, these studies suggest that the size of a pool, if too small, may constrain certain behaviors in zoo-housed penguins, which has direct implications for their welfare.

This study occurred between the months of November and January when the air temperature ranged between −3 and57 °F (−20 to 14 °C). Consequently, the pool temperatures also varied considerably, ranging from 46 to 60 °F (8–16 °C). It is possible that these cold temperatures impacted the penguins' swimming activity as the temperatures in southern Africa, where this species naturally occurs, tend to be warmer, around 95 °F (35 °C) [23]. However, we found that the penguins swam more, both in terms of the number of swim bouts as well as the total time spent swimming, when the air temperatures were between 31 and 40 °F (−1 to −4 °C). These air temperatures were in the mid-range of what the penguins experienced throughout the course of this experiment. Still, it is possible that the penguins' response to the bubble curtain may have been different if tested during months with warmer temperatures, and we plan to examine this possibility in future research.

Our approach of remotely monitoring the swimming behavior of penguins allowed us to obtain more information about their activity patterns across daytime and nighttime periods. Studies on the behavior of zoo-housed animals are typically limited to zoos' opening hours of operation (i.e., during the day), which consequently limits our knowledge of these animals and how they behave throughout the entire 24 h period [18]. Remote monitoring over 24 h periods can provide valuable insights about how zoo-housed animals behave [24,25], which can guide decisions that enhance their welfare. Remote monitoring during this study revealed at least three individual penguins swam overnight between the hours of 0:00–6:00. The color-coded armbands used to identify individual penguins were not distinguishable from the video camera, so the IDs of these penguins could not be determined. However, one penguin with an armband on the left side was frequently observed swimming around 2:00 during Phase 2 of the study. The side of the armband and the similarity in swimming time suggests this was likely the same individual being observed. On a few occasions, a second penguin joined, and on one occasion a third penguin joined as well. This overnight swimming behavior was not observed in Phase 1 of the study when the bubble curtain was off; it spiked during Phase 2 when the bubble curtain was first turned on, and then tapered off in Phase 3 and Phase 4. This pattern suggests that the initial introduction of the bubble curtain may have caused the penguins to avoid the bubble curtain and swim in the middle of the night when the bubble curtain was turned off. However, due to the lack of reliable individual identification in this study, we cannot determine if the penguins that swam overnight also avoided swimming during the day when the bubble curtain was turned on.

Despite our speculation that some penguins may have avoided the bubble curtain during early exposure, we also anecdotally observed several penguins swimming through and interacting with the bubbles created by the bubble curtain during this same timeframe (Supplementary Materials File S2). The behaviors observed suggest that at least some of the penguins found the bubble curtain enriching and indicate that a bubble curtain could be used to facilitate enriching experiences for some zoo-housed penguins. Importantly, this study highlights how animals have individualized responses to the care and enrichment provided, as has been seen in a wide range of species (e.g., goats (*Capra hircus*) [26]; chickens (*Gallus gallus*) [27]; squirrel monkeys (*Saimiri sciureus*) [28]; dolphins (*Tursiops truncates*) [29]; polar bears (*Ursus maritimus*) [30]; gorillas (*Gorilla gorilla*) [31]), as well as this colony of African penguins [14].

Continued studies on the swimming behavior of penguins will prove useful as we collectively seek to increase some naturalistic behaviors in support of good welfare and

decrease instances of bumblefoot in zoo-housed penguins. There are currently thousands of penguins housed at institutions around the world, including 3600 individual African penguins across 130 institutions globally [32]. These numbers highlight the value and need for successful strategies to increase swimming behavior in zoo-housed penguins. It is possible that the use of a wave machine that more strongly resembles the water turbulence naturally experienced by many penguin species, including African penguins, could entice penguins to swim for longer durations. Future studies should be cognizant of the impact that air temperature and pool temperature may have on penguin swimming activity. Additionally, future studies should record individual penguin IDs to account for individual differences in swimming activity and potential changes in individual swimming activity across experimental phases.

5. Conclusions

In conclusion, our experimental addition of a bubble curtain to the outdoor pool of an African penguin habitat did not result in increased swimming behavior. While some penguins interacted with the bubble curtain, others appeared to actively avoid it and the change in swimming behavior was certainly not sufficient to alleviate concerns regarding foot health. The range of responses observed from the penguins indicates that there is likely not a single solution to increase the amount of time that penguins spend swimming; effective strategies will likely involve providing options to accommodate individual differences and enhance the welfare of all individuals.

Supplementary Materials: The following supporting information can be downloaded at: https://zenodo.org/record/8193648, File S1: Top-down view of outdoor penguin habitat at Lincoln Park Zoo, modified from Saiyed et al. (2019). The red box denotes the approximate view visible from the Wyze camera. The dashed blue line in the pool denotes the approximate placement of the bubble curtain. The numbered circles denote nest boxes that connect to the indoor portion of the habitat, which penguins had access to 24/7. A north indicator and approximate 1 m scale are included. File S2: Model summaries for the best fitting models for each predictor variable (swimming time and maximum number of penguins in the pool). File S3: Video compilation of African penguins (*Spheniscus demersus*) at Lincoln Park Zoo interacting with a commercially available bubble curtain in the outdoor pool of their habitat.

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Institutional Review Board Statement: This study was approved by the Lincoln Park Research Committee, the governing body that oversees all research conducted at the institution (addendum to 2018-019: Behavioral Monitoring at Lincoln Park Zoo on 27 October 2022).

Data Availability Statement: Data provided upon request.

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Conflicts of Interest: This work has not been published before and is not under consideration elsewhere. All authors have approved this version of the manuscript and declare no conflict of interest.

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