Hear it here: Built environments predict ratings and descriptions of ambiguous sounds

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Abstract

The built environments we move through are a filter for the stimuli we experience. If we are in a darker or a lighter room or space, a neutrally valenced sound could be perceived as more unpleasant or more pleasant. Past research suggests a role for the layout and lighting of a space in impacting how stimuli are rated, especially on bipolar valence scales. However, we do not know how affective experiences and descriptions of everyday auditory stimuli are impacted by built environments. In this study, we examine whether listening to a series of ambiguously valenced sounds in an older, darker building leads these sounds to be rated as less pleasant - and described using more negatively valenced language - compared to listening to these sounds in a newer building with more natural light. In a between-subjects design, undergraduate participants at an older building or a newer building ($n_{\mathrm{Old}} = 46$, $n_{\mathrm{New}} = 46$; $n_{\mathrm{Female}} = 71$, $n_{\mathrm{Male}} = 18$, $M_{\mathrm{Age}} = 21.18$, $Range_{\mathrm{Age}} =$ 17-38) listened to ten sounds that had previously been rated as ambiguous in valence, then rated these sounds on a bipolar valence scale before being asked to describe, in writing, how they felt about each sound. Participants rated sounds as being more pleasant at the New site compared to the Old site, but the sentiment of their descriptions did not differ between sites. However, bipolar scale ratings and description sentiment were highly correlated. Our findings suggest a role for the features of built environments in impacting how we appraise the valence of everyday sounds.

Author summary

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Introduction

The built environments we inhabit in our daily lives affect how we perceive the world around us. If you are in a dark building with narrow hallways and hear a dog barking, you may feel more threatened than if you heard a dog barking in a bright, airy space.

Theories of embodied cognition [1] posit that cognitive processes, including our interpretation of the origin and valence (affective qualities) of stimuli, are situated in the active engagement of an agent within an environment. Auditory stimuli, unlike many kinds of visual stimuli, are especially susceptible to misinterpretation because of greater challenges in localizing the source of a sound in our environment compared to a visual stimulus [2]. The perceived valence of a sound can be contextually shifted in a laboratory context depending on the extent to which the sound can be localized [3] and controlled [4] by the person experiencing them. The way in which we interpret a sound could also be influenced not only by its present spatial environment, but also by our understanding of what the sound means to us. Hearing a certain sound that is associated with a negative experience may evoke a strong emotional response regardless of present context and may, in fact, evoke a past spatial and temporal context instead [5]. Additionally, our perception of an ambiguous sound could be an indicator for how we interpret the environment in which it is heard [6]. As such, it is important to evaluate how past and present experiences of sounds impact how they are rated and perceived. Valence rating scales allow participants to rate the degree to which these sounds elicit positive or negative sentiments. While these scales give us important information about quantifiable negative or positive aspects of an experience, they may not fully capture qualitative experiences of sounds in different built environments. Furthermore, we do not yet know how experiences of auditory stimuli are reflected in the context in which they are presented, or in descriptions of features and affective states associated with these stimuli.

Beyond the lab, the features of a built environment - especially its architectural features, such as the size of a room or the amount of lighting available - can promote specific behaviours or cognitive states. We can form a unified representation of this environment that modulates how we experience stimuli and make decisions within it [7]. Past studies have identified ways in which spaces with distinct features can promote differing behaviours. For example, Wu et al. [8] found that being in a building that promoted environmental sustainability increased the likelihood of participants selecting the correct bin in which to correctly recycle products, while improving accessibility to compost bins can increase recycling behaviour in residential contexts in the long term [9]. Similarly, a room in an older building with no natural lighting may be less pleasant compared to a room in a new building with plentiful natural lighting. Thus, we might respond to stimuli in the less pleasant space more negatively, as these features could change how we determine the sources of stimuli - like sounds - [10] and whether they should be considered as threatening [11]. No one element of these environments drives the behaviour; the general representation of the built environment could impact how we appraise stimuli within it. Past studies primarily focus on changeable features of the built environment to promote specific behaviours, or feature positive or negative stimuli. Furthermore, they typically rely on self-report or behavioural measures of responses to these stimuli, whereas our experiences of these stimuli may draw on a variety of past and present experiences that cannot be captured by these traditional measures alone. Additionally, we engage with stimuli in our environment in distinct ways depending on whether we are in a laboratory context or a more naturalistic setting. For example, eye gaze behaviour greatly differs depending on whether a participant is in the presence of a live compared to a videotaped confederate [12], and virtual, constructed environments do not elicit participant responses such as contagious yawning when live contexts do [13]. Accordingly, the ways in which participants respond to ambiguous stimuli could differ greatly if they are in a laboratory context vs. a more naturalistic setting - and whether they experience them in a highly controlled space vs. in built environments with differing acoustic and lighting properties. However, we do not know the extent to which the effects of one's context on perceived stimulus valence generalize from the laboratory to naturalistic contexts. Such experiences could be captured by asking participants to describe how they feel about the stimuli they experience in each space, taking a phenomenological approach [14] to understanding how sounds may be differentially experienced depending on the features of the built environment in which they are heard.

Design features of a space, including lighting and materials used, can reduce the unpleasantness of auditory stimuli with aversive features [15]. These real-life experiences highlight the importance of moving beyond the computer screen and the lab when evaluating responses to everyday stimuli. However, many stimuli we experience, such as dogs barking or a phone ringing, are highly open to interpretation depending on context. Furthermore, if our experience of these sounds reflects the built environment in which they are heard, then evaluating how the valence of these sounds is judged could shed light on our experiences and judgments of diverse built environments. Yet the role of architectural features - that comprise a built environment - in shifting how we rate and describe the valence of these common stimuli has yet to be investigated.

In the present study, we take an ethological approach [16] to explore whether common stimuli are rated and described as positive or negative in different architectural environments. Participants completed the study at one of two different sites - a windowless room in an older building and a windowed room in a newer building. In a windowless room, participants have less of a reference for the outside world compared to a room with windows, which could cause the space - and stimuli experienced within it - to be judged as less pleasant. Furthermore, if one has to walk through an older building to reach this study room, one will experience more antiquated infrastructure that might be more effortful to traverse (i.e. narrower staircases or a smaller elevator) potentially driving a more negative appraisal of stimuli experienced in that space as compared to in a newer building. Thus, these two spaces offer contrasts in the environments that could drive stimulus interpretations. At each site, participants listened to a series of sounds that have previously been rated as neutral with a high standard deviation on a bipolar scale, indicating varied representations of valence [17]. Such sounds would not have acoustic content (i.e. frequencies) that would make them strongly pleasant or painful to listen to by themselves [18], allowing their perceived valence to be shifted by the built environment in which they are heard. Furthermore, these sounds would be open to interpretation based on contexts in which they were previously experienced, and aversively or pleasantly valenced experiences associated with these past contexts [11]. Participants first rated each sound for valence on a bipolar scale, which has been shown to disentangle valence from arousal information in emotionally salient stimuli more effectively than unipolar scales for each valence dimension [19]. These sound ratings were used to establish a self-report baseline for how participants rated the valence of each sound in different built environments. Then, to explore how participants describe their experiences of each sound, we asked them to write out how they felt about each sound. Their responses could then be evaluated for sentiment information - whether they used more positive or negative language to describe sounds depending on the context [20]. Last, they indicated the route they used to enter the building where the study was located, to evaluate participants' awareness of the features of their built environment. This allowed us to evaluate the role of movement through architectural spaces in impacting how participants experience ambiguous sounds.

Materials and Methods

Participants

We powered our study for a medium effect of 0.4 for a difference in bipolar sound ratings between sites. Using a bootstrapped power analysis for 1000 iterations in the

Table 1. Demographic information for all participants, by site and sex.

Site	*Sex*	*n*	M_{age}	SD_{age}	Min_{age}	Max_{age}
New	Female	35	21.91	4.09	18	38
	Male	10	20.70	1.7	18	24
	Other	1	21.00		21	21
Old	Female	36	20.63	3.34	17	36
	Male	8	21.62	1.69	19	24
	Other	2	19.00	0	19	19

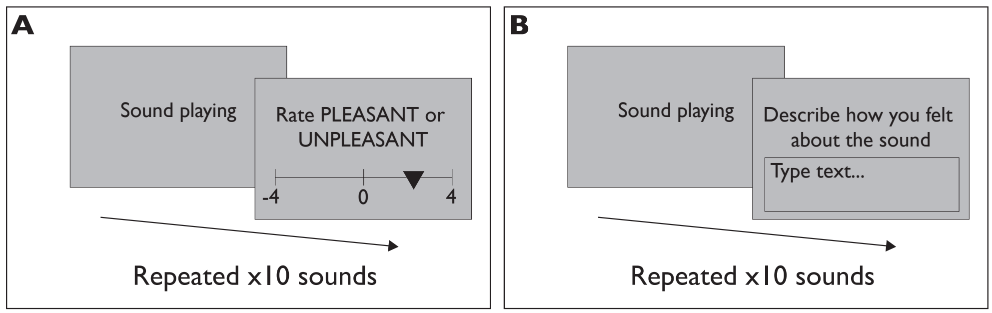

Fig 1. Diagram of the trials in each phase of the task. In the first phase (A), participants listen to and rate the valence of 10 sounds on a bipolar scale. In the second phase (B), participants listen to the same 10 sounds and describe in text how they feel about the sound.

Superpower package in R [21], we obtained a target sample size of $N = 64$ per site with a power level of 0.8. We recruited $N = 97$ psychology undergraduate participants from the Human Subject Pool at the University of British Columbia. All participants received bonus points towards their courses. Of these, $N = 5$ participants were unable to finish the task because of equipment errors. As such, we analyzed data from $N = 92$ participants ($n = 18$ male, $n = 71$ female, $n = 3$ other; Table 1). This study was approved by the research ethics board at the University of British Columbia with code H10-00527.

Stimulus Presentation

All visual stimuli were presented on a Lenovo ThinkPad P52s laptop with a 15.6 inch display (resolution: 1920x1080) running Windows 10, via the Pavlovia online study platform using PsychoPy 2021.2.3 (RRID: SCR_006571) [22]. Auditory stimuli were presented via the task through a set of two Dell A215 stereo speakers. In order to create the impression that the auditory stimuli originated from the room as opposed to from the computer - and was situated within the architectural context - the left channel speaker was placed directly behind the participant, while the right channel speaker was placed directly to the right of the participant. The volume on these speakers was set to maximum, while the computer volume was set to a level of 32 in Windows.

Stimuli

The stimuli in our study were a series of ten .wav audio files with a 6 s duration each. These auditory stimuli were selected from the International Affective Digitized Sounds system (IADS-2; [17]). All sounds selected had a mean rating between 5 and 5.9

(neutral point) on a 10-point Self-Assessment Manikin scale rating from completely unhappy to completely happy [17], and had a standard deviation in their pleasure rating of at least 2. These sounds were played in two different random orders twice through the task: once for participants to rate how they felt about the sound on an onscreen bipolar scale, and again for participants to describe how they felt about the sound.

Procedure

Participants came to the study room in-person to complete the task. In order to provide two distinct architectural environments in which the sounds would be heard, the study took place in two locations on the campus of the University of British Columbia. In the old building condition (Old), participants completed the study in a 2.00m x 3.00m room in a 1980s-era building on campus with a fully covered window and no natural lighting. In the new building condition (New), participants completed the study in a 2.00m x 3.00m room in a 2010s-era building on campus with two large windows and plentiful natural lighting. The laptop and speakers used, as well as the orientation of the participant relative to the door in the room, were kept consistent between sites. In both conditions, the participant was seated at a desk in front of the laptop. After reviewing the consent form and filling out demographic information and a questionnaire about COVID-related stress, participants began the experimental task. In the first block of the task (Fig. 1A), participants listened to a series of ten sounds presented in a random order. After hearing each sound, participants were instructed to rate the sound on how pleasant or unpleasant it was on a scale from -4 (most unpleasant) to 4 (most pleasant), with a neutral point at 0. In the second block of the task (Fig. 1B), participants heard the same ten sounds in a differently randomized order and were instructed to describe how they felt about each sound in 1-2 sentences by typing in an on-screen text box. Participants were not reminded of their sound ratings in this stage. Afterwards, participants were sent to a debrief survey in which they were asked to indicate how pleasant the room they were currently in was, on a 7-item Likert scale from "Very unpleasant" to "Very pleasant" with a neutral point. They were then asked how familiar they were with the building they were currently in, on a 7-item Likert scale from "Not familar at all" to "Very familiar" with a neutral point. They were further asked which entrance they used to enter the building (north, south, or side entrance) and, once in the building, whether they used the stairs or elevator to reach the study room. Participants then received credit towards their psychology courses.

Analyses

We conducted all analyses using R 4.3.1 "Beagle Scouts" [23] through RStudio [24].

Our primary predictor variables was site - that is, whether the participant completed the study in an older, windowless room in a darker, concrete building (Old) or a newer, windowed room in a brighter, more modern building (New). Our secondary predictors were room pleasantness, operationalized as the participant's rating of the room's pleasantness; site familiarity, operationalized as the participant's familiarity with the building in which they were completing the study; entrance used, operationalized as the entrance participants used to arrive at the study; and path, operationalized as whether participants used the elevator or stairs to arrive at the study. Our primary dependent variables were 1) bipolar scale rating, operationalized as the participant's rating of each sound's valence on a bipolar scale; and 2) sentiment score, operationalized as the sentiment of each body of text that participants used to describe how they felt about each sound. We calculated sentiment scores by running the VADER sentiment analysis R package [20] on each body of text that participants wrote, and obtaining the overall sentiment of each sentence.

We compared bipolar scale and sentiment analysis ratings by site using a series of t-tests comparing the two rating types between sites, followed by a multi-level model predicting bipolar ratings and sentiment scores from rating type (bipolar rating vs. sentiment score), site, room pleasantness, site familiarity, entrance used, and path as fixed effects and participant as a random effect. We further evaluated the correlation between bipolar ratings and sentiment score to explore whether both scales captured information about perceptions of sound valence. All statistical tests were Bonferroni corrected for multiple comparisons.

Results

Differences in sound ratings by site

We first asked whether participants rated sounds as being significantly more pleasant on the bipolar scale at the New site relative to the Old site, to see if built environment can impact how participants rate ambiguously valenced sounds on a conventional self-report scale. A two-sample between-subjects t-test comparing bipolar scale ratings between sites revealed that participants rated all sounds as being significantly more pleasant in the New site compared to the Old site ($t(89.55) = 3.32$, $p = 0.005$, $d = 0.68$) (Fig. 2A).

We next evaluated whether the sentiment of participants' descriptions of how they rated sounds was significantly more positively valenced at the New site compared to the Old site, to determine whether built environment shifted the content of unprompted descriptions of sounds by participants. A two-sample between-subjects t-test comparing bipolar scale ratings between sites revealed that the sentiment of sound descriptions did not significantly differ between sites ($t(88.68) = 1.41$, $p = 0.653$, $d = 0.29$) (Fig. 2B).

Predictors of sound ratings

The participant experience of each site may have differed on a variety of factors, including their route to the study room and their familiarity with the site itself, which could impact the built environment in which sounds were experienced. We therefore conducted a multi-level model analysis to investigate whether experiences of the built environment directly explained sound ratings and sentiment scores. This analysis revealed that site, rating scale type, and whether the south vs. north entrance to the building was used significantly predicted sound ratings (Table 2; Fig. 3) such that bipolar sound ratings, but not sentiment scores, were lower in the Old site compared to the New site and participants who used the south entrance to both sites generally rated and described the sounds as being more pleasant. Room pleasantness, site familiarity, whether the side entrance to the building was used, and whether stairs or an elevator were used did not significantly predict sound ratings. Given that the site influenced ratings but not the valence of descriptions, we further examined the degree to which ratings and sentiments were correlated. A correlation analysis revealed that participant ratings on bipolar scales were significantly correlated with the sentiment of their descriptions of the sounds ($t(92) = 8.31$, $p < 0.001$, $r = 0.65$).

Discussion

We investigated whether the architectural environment in which an ambiguously valenced sound is heard influences how participants rate the valence of the sound and the sentiment of how they describe it. We found that, in an older building in a windowless room with no natural lighting (Old), participants rated all sounds as being significantly less pleasant than participants in a newer building with a well-lit room

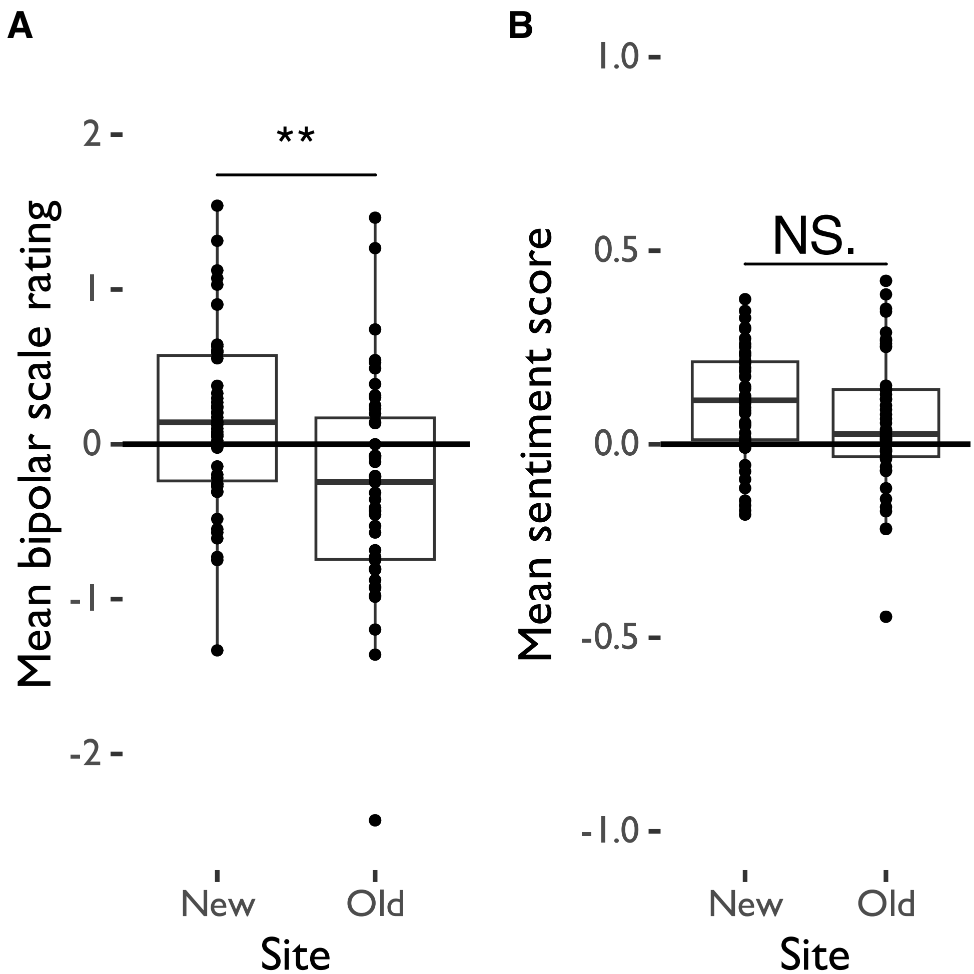

Fig 2. Mean sound ratings from (A) bipolar scale and (B) sentiment analysis scores by site.

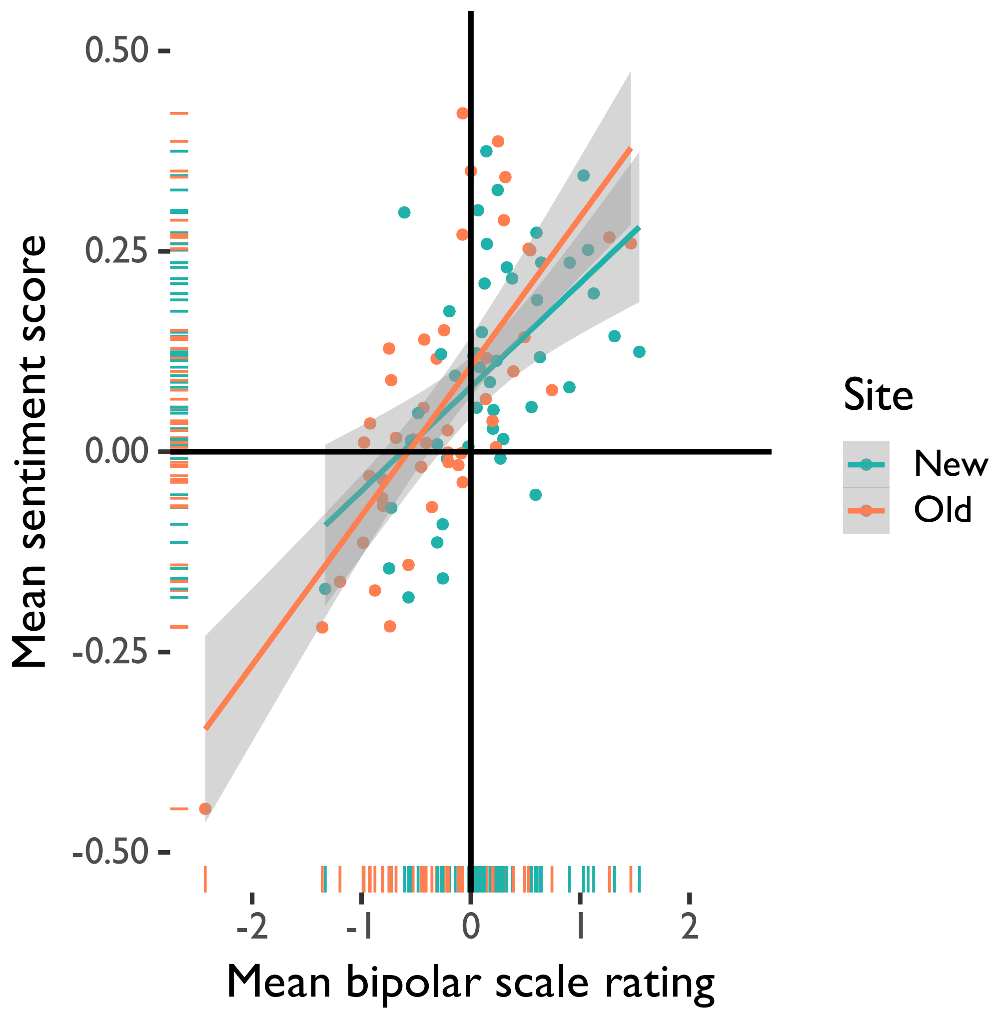

Fig 3. Linear regression of mean sound ratings from bipolar scale and sentiment analysis scores by site.

Table 2. Multi-level model analysis results for sound ratings. AIC = Akaike information criterion, BIC = Bayesian information criterion, ICC = intraclass correlation, RMSE = root mean squared error.

	Multi-level model: Rating
(Intercept)	0.09
	(0.19)
Pleasantness of room	−0.01
	(0.03)
Familiarity with building	−0.02
	(0.03)
Side entrance used	0.11
	(0.10)
South entrance used	0.22*
	(0.11)
Stairs vs. elevator	0.07
	(0.10)
Rating type	0.13*
	(0.06)
Site	−0.23*
	(0.10)
SD (Intercept participant)	0.24
SD (Observations)	0.41
Num.Obs.	184
R2 Marg.	0.102
R2 Cond.	0.338
AIC	282.8
BIC	315.0
ICC	0.3
RMSE	0.36

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(New). However, when participants described how they felt about the sounds, the valence of the sentiment of these descriptions did not differ between sites. Participants did not use more negatively valenced language to describe sounds at the older site compared to the newer site.

Our findings align with past work showing that qualities of the built environment - such as the features and design of a building - can impact how we approach stimuli and make decisions. For example, Wu et al. [8] discovered that being in an environmentally friendly building promoted increased engagement in more environmentally sustainable behaviours such as recycling, even when individuals were unable to explicitly identify the building as environmentally friendly. Similarly, although the sites for our study did not have as many explicit cues meant to nudge specific behaviours - such as rating a stimulus as more or less aversive (e.g. no signage or interventions that promoted more positive or negative appraisals of sounds) - their differences still had a significant effect on how participants rated the aversiveness or pleasantness of sounds. Each site had distinct architectural, acoustic, and affective features, which may have impacted the decisions that participants make about stimuli they experience in each site. Participants may have offloaded some of the cognitive effort required to make a judgment about a sound to how they interpreted its context [1]. In the Old site, participants navigated a predominantly concrete building to reach a study room that was highly enclosed and had no natural lighting. In contrast, to reach the naturally lit study room in the New site, participants navigated a bright and airy space. As such, the less pleasant Old site may have drawn attention to the more negative attributes or associations of an otherwise neutral, everyday sound, with the New site comparatively enhancing the positiveness of how participants interpreted the sound. Participants rated and described sounds more positively when using the south compared to the north entrance of the building. The south entrance of each building was generally further away from the test site than the north entrance. Participants entering the building by this route may have experienced more of the built environment that would impact their ratings of the sounds. Information that is encoded about architectural features could differ depending on the entrance participants use to reach the study, priming how participants engage with stimuli they experience in the space - even if participants are unaware of the effects of the space on their sound ratings and descriptions. Thus, participant ratings of sounds could be proxies for their experience of the architectural context in which the sounds were heard - enhanced by the amount of time they spent moving through the space. These findings highlight potential latent roles for the combined features of an architectural context in impacting not only behaviours but also experiences of stimuli.

The attribution of site to the differences in sound interpretation may be challenged by the lack of difference in sentiment ratings between sites in participant descriptions of sounds. In contrast, the bipolar rating scale invites interpretations of a sound on an axis of negative to positive valence. Bipolar rating scales of emotionally salient stimuli have been shown to be dissociable from arousal [19], while participant descriptions of their experiences of sounds could range much more widely and be more nuanced. As the sounds used were not highly positively or negatively valenced and had a wide range of ratings when originally normed [17], it is not surprising that this wide range of experiences would be reflected in how they were described. In spite of the finding that only bipolar sound ratings differed between sites, sentiment scores were significantly correlated with bipolar ratings. The participant descriptions - from which sentiment scores were derived - captured a wider variety of experiences than valence information; however, the valence information that was present was congruent with that of bipolar ratings. This finding highlights the importance of using both quantitative and qualitative research methods in complementary ways - as each method can capture different aspects of how a built environment can impact perceptions of ambiguous sounds.

Further to this point, many participants drew on their memories of past experiences with the sounds, beyond merely describing how they experienced the sound in their present context. For example, one of the sounds was of a dog barking. While some participants described the sound outside of any temporal context (e.g., "This sound is not that pleasant because it feels like the dog is sensing danger", others drew on past experiences with dogs to inform their present appraisal of the experience (e.g. "[I] quite like this one. it sounds like what i would hear from my childhood bedroom."). Other sounds had ambiguous sources and meanings to different participants. For example, one sound used sounded like nighttime in a rainforest to some participants ("This sound feels like home, during nighttime at a tropical country, it could be soothing to me."); to others, it sounded like an unpleasant dental tool ("[This] sound makes me uncomfortable. it reminds me of the drying device used at the dentist. [The] sound makes my mouth and skin feel uncomfortably dry listening to it."). Participants did not reference the architectural context in which they heard the sounds at any point. However, this diverse array of participant responses reflects the variety of reasons that participants may have had for rating sounds as more or less pleasant - ratings that did interact with the architectural context in which they were presented. Queries about the qualitative experiences of stimuli in our environment augment information from self-report scales and offer rich phenomenological information [14] about whether participants situate these stimuli in their present context or, instead, draw on past contexts and experiences, when interpreting how they feel about these stimuli.

We must consider a number of qualifications when interpreting these results. First, because of the nature of the sites used, their room configuration could not be kept perfectly consistent. In the Old site, although the participant and speaker positions were held constant across all participants, the arrangement of other furniture and objects in the room underwent minor changes over the course of the study (e.g., a chair was pulled out rather than tucked under a desk). However, these changes did not affect the lighting, space available, or layout in the room, and the qualitative impression of the space was maintained throughout the study. Similarly, in the New site, the furniture stayed relatively constant; however, changes in natural lighting throughout the day during different runs of the study may have impacted the room's character. Furthermore, for $n = 24$ participants, the room partition on one wall in the New site was locked in an open position, causing other parts of the room to be visible. However, the rest of the space was the same in appearance to this study room. Second, in both sites, loud conversations and sounds outside the room were reported by $n = 5$ participants. However, such experiences were typical of these sites and did not interrupt the study. Third, the sounds used were highly open to interpretation in terms of valence. Although this was by design, it may have weakened potential effects of site compared to using sounds that had an established positive or negative valence - especially as previous studies have investigated reductions in the aversiveness of negatively valenced sounds depending on properties of the built environment [3]. Last, the order of the sound ratings and descriptions were not counterbalanced across participants. As such, participant descriptions of sounds may have been informed by their memory of how they rated the sounds. However, the lack of a significant difference in the sentiment of sound ratings between sites - even when sound ratings on the bipolar scale significantly differed - suggests that the qualitative component of the study still captured distinct information about participants' sound experience beyond merely recapitulating the sound ratings. On the other hand, the robustness of the site difference in sound ratings in spite of these environmental differences speaks to how the overall feel of an architectural space can strongly drive perceptions of stimuli experienced within that space, and highlights the insights that can be derived from evaluating how stimuli are interpreted in real-world, uncontrolled environments.

Future studies could investigate whether and how individual attributes of a built environment drive quantitative and qualitative evaluations of participant experiences of sounds. For example, manipulating the level of lighting in a room could impact perceived sound valence through changes in the perceived friendliness of a context [15], while reducing one's ability to attribute a sound to a source could increase its aversiveness [3,25]. Furthermore, given the increasing relevance of virtual and augmented reality in our everyday lives, future work should also explore similarities and differences in how sounds are rated and described in virtual vs. real-life spaces [13]. These projects would help us better understand whether and how these findings about stimuli ratings apply beyond the computer screen and beyond the lab, in more naturalistic settings.

Our study's findings emphasize the importance of considering the role of the architectural environment when presenting participants with ambiguously valenced, everyday auditory stimuli. In two buldings that frequently serve as experiment testing spaces, we show significant differences in how sounds are rated while controlling for the familiarity and perceived pleasantness of the built environment. Furthermore, our findings suggest a potential role for past experiences interacting with present context when participants give rich descriptions of their experiences of everyday sounds. Experiences of stimuli within architectural contexts could tell us about how the contexts themselves are perceived and experienced, shedding light on the role of features like lighting and acoustic qualities in determining how comfortable we feel in real-world spaces. These results could inform future conversations on how to create built environments that are amenable to pleasant experiences, and emphasize the important of context when interpreting stimuli both inside and outside the lab.

Data and code availability

All task code, stimuli, data and code used to generate this manuscript and the figures are available at `https://osf.io/wysdb/`.

Legend

Figure 1. Diagram of the trials in each phase of the task. In the first phase (A), participants listen to and rate the valence of 10 sounds on a bipolar scale. In the second phase (B), participants listen to the same 10 sounds and describe in text how they feel about the sound.

Figure 2. Mean sound ratings from (A) bipolar scale and (B) sentiment analysis scores by site.

Figure 3. Linear regression of mean sound ratings from bipolar scale and sentiment analysis scores by site.

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