Birdbox: Exploring the User Experience of Crossmodal, Multisensory Data Representations

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ABSTRACT

We contribute to an improved understanding of how physical multisensory data representations are experienced and how specific modalities affect the user experience (UX). We investigate how people make sense of Birdbox, a crossmodal data representation that employs combined haptic-audio, audio-visual, or visual-haptic output for data about birds. Findings indicate that participants preferred haptic output for the bodily experience it triggered. Participants further created their own mappings between data and modality; haptic was mapped to aggression, and audio to speed. Especially with (soft) haptic output, Birdbox was experienced as a living entity. This can also be seen in participants' bodily interactions, holding Birdbox as if it were a small bird. We contribute to a better understanding of the UX of different modalities in multisensory data representations, highlight strengths of the haptic modality, and of metaphorical understandings of modalities.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Interaction techniques**.

KEYWORDS

UX, InfoVis, VIS, embodied interaction, sensory modality, haptification, physicalisation, metaphors

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1 INTRODUCTION

When asked to imagine data representations, most people will first respond with examples of visual depictions, such as bar graphs and pie charts. However, data representations can take any sensory modality—for instance, through sound [2], haptics [6, 55], or smell [7, 40]. Increasingly, research has focused on data representations that use other modalities than the visual, e.g. [16, 27, 28, 44]. Although often used on their own (mono-modal), modalities can be combined as well. Such multisensory data representations [20] aim to provide data insight by encoding the data in more than one representational modality and requiring a minimum of two sensory channels to interpret the data [20]. Previous research has explored the design space of multisensory data representations –highlighting which aspects of the haptic, auditory, and visual modality can be used [37, 38]– and indicated that they can communicate an increased number of data characteristics compared to data visualisations [50].

The User Experience (UX) of data representations is an emerging field of research. We here build on the work of Hogan et al. [16–18], which investigated how representational modality influences how people interpret and experience a physical multisensory data representation. In contrast to other fields –such as Virtual Reality (e.g. [9, 41]–, the UX of modalities in physical data representations is still an open research field.

Our work explores how a physical, handheld multisensory data representation –with haptic, audio, and visual output– affects how people make sense of and experience the represented data. We investigate this through *Birdbox*, a cubical object that represents the noise pollution, droppings, and aggression levels of six bird species which are considered an urban pest. Birdbox is a *cross-modal* design [21], that communicates the same data (e.g. noise levels of birds) through different combinations of modalities (audio-haptic, haptic-visual, or audio-visual). Twelve participants explored Birdbox and the data in pairs, and were then interviewed. Our findings confirm previous research [16, 17], in that people respond more emotive to haptic and audio output. This is further illustrated through participants' bodily interactions and responses to these representational modalities, such as holding Birdbox like a small bird. Our analysis further shows that participants preferred the haptic output and that they often made up their own data mappings between output modality and data. The contribution of our work lies in highlighting the role of the haptic modality, showing that it enhanced engagement and created the impression of a living artefact. We further add insight on metaphorical understandings of modalities, supporting the hypotheses of modality-data congruences.

2 BACKGROUND

2.1 Multisensory Data Representation

Multisensory data presentation is an umbrella term [20] that includes concepts such as *sensualisations* [39], *sensifications* [50], and *perceptualisations* [8]. Previous research has indicated that multisensory data representations can enhance learning through lower

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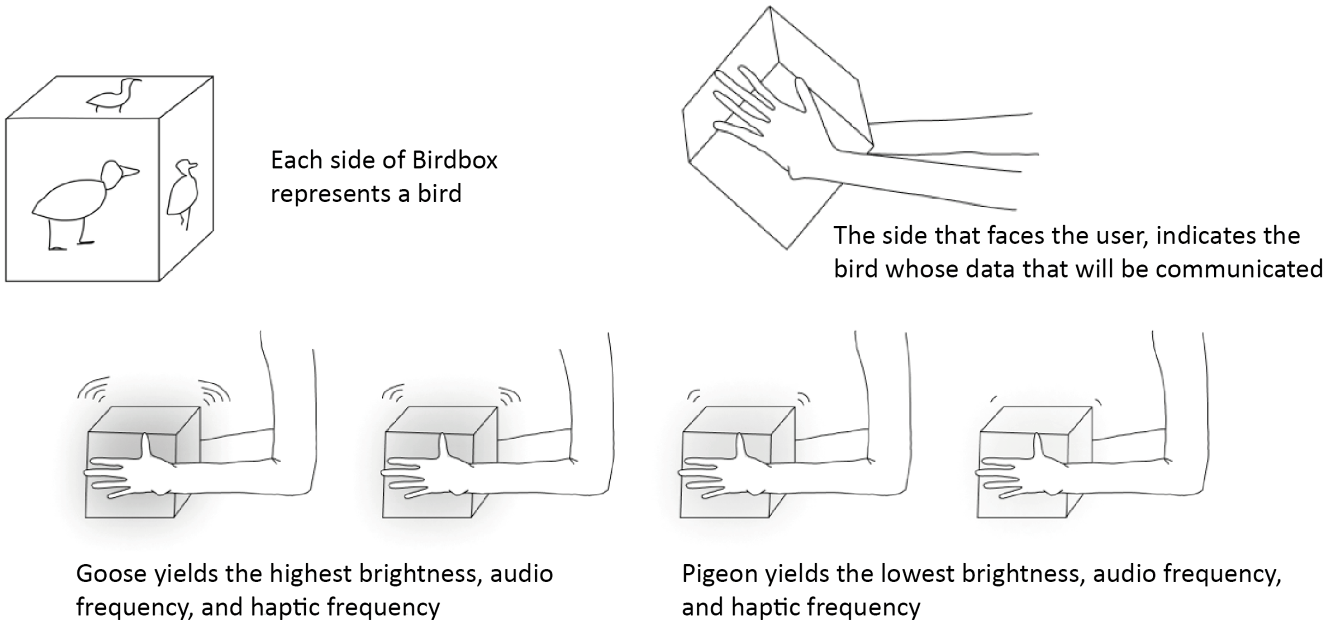

Figure 1: The interaction with Birdbox. Each side of the cube depicts a kind of bird that is considered an urban pest. By rotating the cube, users switch between species; the side facing them contains the data currently selected. Birdbox uses combinations of two modalities to represent data. Our study investigated audio-haptic, audio-visual, and visual-haptic output.

mental effort [49] and communicate a wider range of data characteristics [50]. Whereas multimodal representations use two or more representational modalities to communicate *different* data, *crossmodal representations* [21] use the representational modalities for the *same* data. Outside the field of data representations, research has found that crossmodal displays are intuitive and increase engagement with the task at hand [25, 36].

Despite the strengths and opportunities of multisensory representations, little is known regarding their user experience [19, 36]. Prior work explored their usability (e.g. [13, 21, 22]), showing that people can easily and effectively understand data represented through the haptic and auditory modality. Moreover, these improve users' performance over a visual-only interface [21]—although this does depend on the environment (e.g. a noisy environment makes it harder to understand auditory output) [22].

The work of Hogan et al. [16–18] offers first insights regarding the UX of mono-modal representations. This work explored how people experience and interpret data represented through audio, haptic, or visual feedback [16–18]. It found that people respond more emotionally to auditory and haptic output, which also stimulated and engaged the human body in the process of data interpretation. The researchers hypothesised that auditory and haptic data representations may be more successful when combined in a crossmodal data representation [16, 17]. To explore this hypothesis and the UX of crossmodal multisensory data representations, our study explores three crossmodal combinations: audio-haptic, haptic-visual, and audio-visual, and examines how these are interpreted and experienced.

An area related to multisensory data representations that has gained traction is that of *data physicalisation*. Physicalisations can be defined as physical artefacts *"whose geometry or material properties encode data"* [29]. While the majority of physicalisations rely on encoding data through shape, such properties can include –for instance– weight, texture, temperature, or scent. Studies have demonstrated the value of physical interaction with physicalisations, indicating that they enhance engagement, lower cognitive load, and foster deeper connections to the data (e.g. [19, 29, 35, 48]). These findings show the potential for data representations that go beyond the 2D visual space (thus including data representations based on non-visual modalities). Data physicalisations are often used when the aim is to foster not just rational analysis, but to evoke empathy, or affective and visceral responses [53]. There is also indication that haptic and auditory representations raise more affective reactions than purely visual representations [16, 17]. This motivates our investigation of the user experience of multisensory data representation, and the design of the study to utilise a handheld cube.

2.2 Bodily Interactions with Data Representations

Previous studies on data physicalisation and other representations which go beyond the visual show bodily reactions to these types of data representations. For example, one study [27] explored how people physically manipulate tokens to create a data representation of bank account data. During interviews, participants gestured, selected elements, or pointed at their representations to communicate their story. Similarly, when Jansen et al. compared visual and physical bar charts, it was found that people used their fingers to *"mark"* relevant parts of the chart, such as relocating previously identified areas [28]. People's ability to touch the physicalisation helped them to make sense of and memorise the data. In another study exploring people's interactions with two crossmodal data-driven artefacts (a cube and a dowsing rod for solar radiation) [19], it was observed that people would contemplatively hold the data cube –taking in its haptic output– and enthusiastically point the dowsing rod into the direction its data came from. Lastly, Hogan et al. found that when talking about their experiences with auditory or haptic data representations, people often referred to their own body whilst describing their experiences and interpretation processes [16]. The haptic modality was *"felt"* by the participants in their hands and chest, whereas audio output was explored by holding the data artefact in various ways (e.g. far away, close to your ear, etc.) to experience how the sounds changed.

As these studies indicate the importance of bodily interactions in making sense of and experiencing physical data representations, we focused on how people interact with Birdbox and their bodily reactions during our analysis.

3 THE DESIGN OF BIRDBOX

Birdbox (see Figure 2) is a cube providing haptic, auditory, and visual feedback in a crossmodal setup, meaning that the same data is emitted via two modalities simultaneously (resulting in three combinations). Choice of basic modalities was based on previous research on the UX of mono-modal data representations [16, 18] and Hoggan et al.'s findings that audio and haptic output work well together, due to their temporal nature [22, 23]. The cube shape was selected as previous cubical representations (e.g. [19, 32, 46]) have been shown to be intuitive to manipulate, since users quickly understand the concept of selecting options by turning and rotating the cube (like a dice).

Birdbox represents data on bird species which are considered urban pests. This data set was chosen as most people can relate it to own experiences and memories of birds –even if not the exact same set of species– from their home country and at their current home. We hoped this would make it relatable, yet offering surprising information—thus keeping participants' interest. Even for German participants (the experiment was conducted in Germany) this would involve novel information, for instance people who do not live at the seashore are rarely aware of sea gulls being noisy and aggressive. The data set was retrieved from the AMES Group [1]. Three aspects of the data set were selected as the most interesting and potentially surprising: (1) the amount of droppings, (2) noise pollution, and (3) aggression levels, and six species selected (feral pigeon, starling, goose, magpie, seagull, and crow). The AMES Group article ranked noise pollution and droppings on a scale from one to five. As Birdbox only represents four data points (to minimise user fatigue), score points five and four were merged. Furthermore, where the original data set scored aggression with text labels (as *"no"*, *"yes but only to other birds"*, *"yes if you antagonise them"*, *"yes, very"*), these were mapped to numeric scores. Table 1 shows the final data set used in the study. The data then was mapped to haptic, visual, and auditory modalities.

Interaction with Birdbox leverages the affordances of cubes [32, 46]—people select a face by rotating the cube. As shown in Figure 1 and 2, each face depicts one bird. By flipping a face upwards, the data of that species is played. For example, the pigeon-side (Figure 2) triggers the highest level of output when investigating droppings, and the lowest output levels for noise pollution and aggression. Data is represented differently in each condition of our study through a combination of two modalities: audio-visual, visual-haptic, or haptic-audio. We chose a combination of two modalities in a crossmodal setting, as previous research indicates that three modalities highers the chance of cognitive overload [12].

Table 1: The data set represented with Birdbox. A numeric score of 1 indicates the lowest level and 4 the highest.

Birds	Droppings	Noise Pollution	Aggression
Pigeon	4	1	1
Starling	1	2	1
Goose	3	4	4
Magpie	2	3	2
Seagull	4	4	4
Crow	1	4	3

A consumer device vibration motor (the Satisfyer 'Sexy Secret' vibrator) was used for haptic output, of which we used four different intensity settings (minimum and maximum intensity, plus two values in between), each giving a continuous vibration signal. The vibrator was chosen for its strong and distinct intensity output. The highest intensity vibration represents the highest data level, and the lowest intensity represents the smallest data level. The vibration motor was centred inside Birdbox, so that vibrations would be equally distributed along all sides of the cube, and was activated over Bluetooth. Visual output was generated using LEDs (Adafruit Neopixel Fairy Lights), where the blinking frequency communicates the data—slow blinking for low levels and fast for high levels. The slowest frequency had the light on for 4 seconds, then out for 4 seconds (in a loop). The next frequency did the same but in 2 second intervals, the third in 0,7 second, and the fastest would flicker in 0,3 second intervals. The initial pilot had revealed that participants often did not take notice of the light intensity levels (the surrounding light apparently distracting from it), and indicated that blinking frequency was easier to notice.

Auditory output was provided via Bluetooth speakers. A simple bleeping sound was utilised, where the repetition of the sound per minute represents the data levels: high repetition (152 'beeps' in a minute) for high levels and low frequency (44 'beeps' in a minute) for low levels.

To keep Birdbox balanced whilst participants rotate it, the Bluetooth speakers were hidden under the table. This ensured quality audio, while keeping Birdbox lightweight and easy to handle. Integrating a quality speaker within the box (in addition to the other components already inside: vibration device held inside an internal box to keep it balanced, LED chain, accelerometer, LiPo battery, Arduino) would have required a much larger box, making it less suited for handheld interactions, and would have added extra weight.

Although Birdbox was equipped with an accelerometer (LIS3DH), we partially resorted to Wizard of Oz for our study. The data from the accelerometer triggered the visual output (lights), which

[1] https://www.amesgroup.uk.com/blog/problem-birds-the-worst-bird-pests-identified-and-ranked/

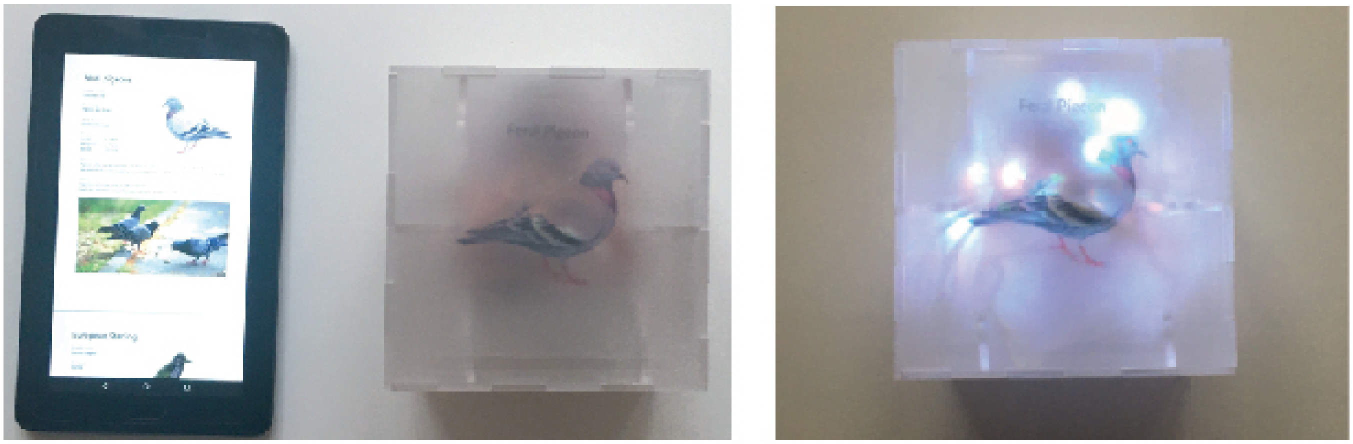

Figure 2: Left: The study setup. Participants received an iPad, where they could look up extra information on the birds for context, and the prototype Birdbox. Here, Birdbox shows data on pigeons. Right: Birdbox's visual modality. The LED's are flickering for the pigeon data. The cube is made from translucent sandblasted acrylic, and images of the bird species as well as a text label were printed on transparent sheets, which diffuses the LED light sufficiently.

changed automatically based on the side facing up. The audio and haptic output were controlled by a researcher, who observed which side was selected. Given both speakers and motor were connected via Bluetooth, this was an easy approach to make the prototype appear fully functional.

4 STUDY SETUP AND DATA ANALYSIS

A total of twelve participants –all students at Bauhaus-Universität Weimar and the University of Music in Weimar– experienced Birdbox in pairs; hence there were six sessions. Using co-participation [42], participants had to verbalise their thoughts whilst interacting with Birdbox. Co-participation (also referred to as 'paired user testing' [47, 54] or co-discovery) is often used as variation of think-aloud, having two participants engage in the task together. Having participants share their sense-making and negotiate decisions with each other creates a more natural situation as when the researcher would repeatedly need to probe for their thoughts, which also risks biasing user behavior and responses. Co-participation may also give insight into the shared experience participants have with the modalities. It has been found to result in rich verbal data and to be experienced as more enjoyable than single-user setups [47]. Furthermore, previous research exploring physical, mono-modal data representations had participants explore the artefacts in groups and found that this resulted in a more natural setting and richer data [18]. This further motivated our decision to use co-participation for our study.

Each pair used Birdbox in three conditions, where each condition had them explore information about the six species in one modality combination. To reduce order effects, the study design was counterbalanced over the crossmodal modalities (see Table 2). The order in which information about birds (droppings, noise, aggression) was given was kept constant in order to have a consistent 'information story' for all participants. Each pair started by investigating dropping levels. One researcher facilitated the sessions and controlled the Wizard of Oz part, noting which side was selected and changing the audio and haptic feedback via remote control. The study closed with a semi-structured interview.

The location of the six sessions was at the home of (one of) the participants, since university labs were closed at the time due to pandemic regulations. As introduction, the participant pairs were told that the study investigates data representation modalities, and that their interactions with Birdbox would be observed. They were informed that they would be given information about bird species concerning droppings, noise and aggression. As ice breaker, they were then asked about their previous experiences with urban birds. Then, the functioning of Birdbox and the modality combinations ('vibration', 'lights blinking', 'beeping sound') were explained. Finally, information sheets were handed out and consent forms signed. Then, the actual study started. The pairs were told to explore the data, starting with droppings. At the start of each data modality combination, the cube was placed in front of the pair along with two cards that stated the data attribute (e.g. 'droppings') and the output type (e.g. 'haptic/audio'). When participants were done, the researcher switched to the next modality and replaced the two cards. In case participants wanted to know more about the birds, they were handed an iPad with additional information (such as weight and height—see Figure 2, left).

During their interactions with Birdbox, participants' hands were filmed to enable analysis of how they held and interacted with the artefact. Moreover, they were occasionally encouraged to think aloud. Lastly, a semi-structured interview was conducted with each pair of participants. This investigated how they experienced the cube design and interaction, whether they could distinguish the four modality levels, how they liked the modality combinations, and whether they remembered the information correctly and found it interesting. Conversation during the exploration and interviews were recorded. All interviews were conducted in English.

Participants were recruited using convenience and purposive sampling. Due to the COVID-19 pandemic and to ensure they felt comfortable interacting in pairs, participants had to either live together (e.g. shared housing) or be partners who frequently visit each other. Participants were between twenty and fifty years old, four women and eight men, with an average age of 28,9 (SD = 7,3).

The co-participative think-aloud and interview data were analysed using reflexive thematic analysis (RTA) [5], following an inductive approach. The first and second author first individually familiarised themselves with the transcripts, highlighting phrases and sentences which stood out to them. This was accompanied with initial open coding. The selected codes were then discussed by the two authors and iterated upon. After some reflection and discussion, the first author constructed and named themes provisionally. These then were discussed with the other two authors. In the final step, the first author finalised the naming, visualised relations between clusters in a thematic map, and distinguished between major and minor themes. In addition, the video data was analysed by looking for patterns in participants' movements and the way they held Birdbox.

5 FINDINGS

We first present findings from the RTA and end by describing participants' bodily interactions with Birdbox. For the UX of the crossmodal output modalities we focus on insights we derived from the interviews, in which participants disclosed their experience with Birdbox and often discussed the modalities on their own. As convention, each quote is followed by a participant and session indicator, e.g. *P1-A* indicating participant 1 session A.

5.1 Perceptions and Impressions

Even though participants' ability to differentiate signal levels was limited, they all enjoyed the study. Participants preferred haptic output as it was more attention-grabbing and bodily experienced, whereas sound was seen as *"technical"* (P5-C). Moreover, participants liked the haptic-audio combination best and the visual modality least. Participants often developed their own mappings between modality and meaning, indicating that they relied on metaphor and analogy to interpret output. Reflecting on participants' interactions, (low-level) haptic output appeared to provide the impression that Birdbox was a living entity. Lastly, participants expressed a wish for more complex data mappings and output.

5.1.1 Readability and Preferences. Our findings indicate limitations regarding participants' ability to differentiate between the signal intensities used in our study. In the interview, they were asked how many different levels they could distinguish per modality. The majority could only distinguish three levels, regardless of modality. Only few guessed that there might be four levels (answering there were '3 to 4 levels'), and this only occurred for audio and visual output. As outliers, one participant believed they could distinguish six levels across all modalities, whereas another thought there were six levels of haptic output. In general, participants had difficulty recalling a difference between the highest and second highest output level for all modalities, merging them into one level. Participants appeared to do best in distinguishing levels for the audio modality (in terms of the number of answers closest to the correct '4 levels'). This might be due to the particular signal design used in our study, but is also consistent with known limitations in the human ability for signal differentiation [1, 4, 14].

Participants expressed a strong preference for haptic output. They preferred the bodily experience it offered: *"I really like the haptic, because I feel like it's more about feeling the result of the data. [. . .] it was more bodily, the experience"* (P1-A) and stated that it grabbed attention more than the co-present modalities: *"vibration was the thing I was very attentive to and the rest was—it was also there, but not that distinguishable."* (P6-C). This could especially be seen in the visual-haptic combination, where participants ignored the visual output and focused their attention on the haptic sensations. Without haptic output (the audio-visual condition), the interaction with Birdbox was not as interesting: *"there was no vibration. So was a bit more boring, I would say."* (P5-C). Furthermore, participants especially liked how the haptic and audio modality worked together, stating that they *"amplify each other when they are combined"* (P3-B), making it easier to understand the data, as described by participant 8 regarding the audio-haptic combination: *"They were two stimulants; it was much more easier to understand"* (P8-D).

Compared to haptic output, audio was considered 'technical' and harder to decipher: *"it was very technical. So we were just concentrating on the, the speed and the repetition, [. . .] because otherwise I think you can't really decode what the cube is telling me."* (P5-C). Similarly, previous work found that audio was seen as 'artificial' and not organic [17]. As caveat in our output design, the utilized beep sound might have been too abstract or binary: *"what does the beep tell me? Doesn't tell me anything. What do you call it, binary information?"* (P6-C).

Finally, the visual modality was least liked. To some, this came as a surprise: *"I thought [. . .] I would like the lights more, because usually I'm more visual, but [. . .] I could take more information from the vibration and noise then from the light."* (P10-E). This sentiment was shared by others, who stated that the light mapping was difficult to differentiate: *"with the sound I can differentiate, but with the intensity of the light it was not as clear as with sound and vibration."* (P7-D). Moreover, it was hard to guess the mapping behind the lights: *"It was kind of hard to decipher. What does the light mean?"* (P3-B). A final reason was given by participant 6, who mentioned that in contrast to audio and haptic, we are used to visual output. As such, it needs something else to stand out: *"I see things all day long. And when there is sound I have more attention for it. Something special. Lighting is just [. . .] it's everywhere. It would be interesting if it would be in a dark room."* (P6-C).

5.1.2 Metaphorical Understandings of Modalities. Despite the clear instructions on modality and information type provided at each stage of the study, participants spontaneously associated mappings between output modality and data meaning. The type of signal appeared to provide suggestions, with stronger vibration being interpreted as 'aggressive' or 'large' and faster beeping as indicating speed. Although they had been informed of the mapping used in each study phase (e.g.: noise pollution; haptic and audio output), participants still came up with their own interpretations. This was especially the case for (strong) haptic output, which participants linked to aggression—even if the data investigated did not concern aggressive behaviour: *"it is easy to link the intensity of vibration with aggression"* (P12-F). This mapping can be seen in the conversation between participant 11 and 12 in Session F, whilst exploring the dropping levels of magpies: *P11: "Okay this one seems to shit a*

Table 2: Overview of the counterbalancing.

Session	Participants	Droppings	Noise Pollution	Aggression
A	1 and 2	visual-haptic	audio-haptic	audio-visual
B	3 and 4	audio-haptic	visual-haptic	audio-visual
C	5 and 6	audio-visual	audio-haptic	visual-haptic
D	7 and 8	audio-visual	visual-haptic	audio-haptic
E	9 and 10	audio-haptic	audio-visual	visual-haptic
F	11 and 12	visual-haptic	audio-visual	audio-haptic

lot." P12: "I think they are kind of aggressive." P11: "You don't know about that yet. You know it shits a lot." P12: "So why is the vibration so intense?" Note that droppings were explored first, so this was the first modality and information type on the birds that this pair encountered. These findings align with previous research towards handheld mono-modal data representations [16, 17, 19].

Haptic output was often linked to the size of the bird, whereas audio data tended to be interpreted as a metaphor for speed (e.g. speed of droppings). The following conversation whilst exploring dropping levels of magpies in the audio-visual modality (in session C) is an example of the latter: *P5: "Slow. That's slow." P6: "Is it to do with their speed?" Interviewer: "You are exploring the droppings for now" P6: "Is this how slow they drop?"*. Furthermore, audio was considered to represent the activity levels of a species (even though this was not part of the data represented via Birdbox): *Interviewer: "What do you understand by the sound?" P7-D (whilst exploring the dropping levels of the pigeon): "how active the animals are?"*.

5.1.3 A Living Entity. Overall, participants enjoyed the interactions with Birdbox, describing it as *"engaging"* (P5-C) and mentioning that *"it was interesting to experience [something which] involves so many ways at once"* (P11-F). One participant remarked that it was *"nice to learn something without effort"* (P9-F). Furthermore, our interviews indicate that participants experienced Birdbox as a living entity. This was especially the case for low-level haptic output: *"vibration was good, calm... feeling nice like a pet"* (P10-F), which was experienced as a heartbeat: *"it's like a heartbeat"* and *"the pumping of the lungs and the beating of our heart"*. While these kinds of responses might partially stem from the data being about living entities, this is in line with findings from previous studies [3, 17], where haptic output was experienced as 'alive'. Our findings from the video analysis of bodily interactions with Birdbox further strengthens this.

5.1.4 Desire for More Complex Mappings. Participants' talk indicates that future representational designs should explore more complex, immersive output. Interestingly, here they mostly had suggestions for the haptic and auditory modality. During sessions, they often looked for further mappings or information—they tried to identify a rhythm, meaning, or pattern in the output. As these were not present, participants expressed disappointment in the lack of complexity: *"sound was just there, beep beep. Like it wasn't much information [...] It was just like one sound, no words, no different tonalities. [...] So I probably lost interest at some point"* (P5-C), and desired a richer, immersive experience. This was reflected in participants' suggestions in the end interviews, e.g. to add bird sounds to Birdbox: *"add the sound of the birds, which will be very interesting because for me, I expected the sound to come"* (P10-E) and *"maybe the audio interaction should be the screaming of the bird, like the sound they really make"* (P4-B). For haptic output, participants suggested to increase immersion by adding patterns: *"I think if the vibration could make some kind of pattern"* (P12-F) and adapting the weight of Birdbox: *"if there would be possible to change the weight of the cube specifically on the birds, that would be also super cool"* (P10-E).

5.2 Bodily Interactions

The impression of Birdbox being a living entity was also reflected in some of the participants' bodily interactions. This is clearest visible in sessions A, C, F, and E. Figure 3 shows the participants of session F interacting with Birdbox, in which they explored the noise pollution from pigeons, gulls, and starlings communicated through audio-visual feedback. Participant 11 cups the cube's bottom and used their thumbs from the side to support it (Figure 3, left). They hold Birdbox delicately as if it is a small bird (right image). They also shrugged their shoulders and softly whistled at the cube when interacting with Starling and Pigeon as if trying to communicate with the cube. When interacting with the data from gulls, participant 12 stroked Birdbox to experience the data (Figure 3, middle). Throughout the entire session, participant 11 and 12 took turns holding the cube while discussing.

Such behaviours were also observed from other participants. For example, participant 5 and 6 in session C only had prior experience with pigeons. When P5 in the audio-visual condition remarked that the starling is the least aggressive bird, P6 remarked in a soft singsong voice: *"Yeah it was the slowest, nice little quiet bird"*, whilst holding Birdbox and stroking its surface delicately—as can be seen in Figure 4 (right). Both participants would also rub the sides of the cube during low levels of haptic output (Figure 4, left). The latter happened in session E as well, shown in Figure 5 (left and middle). Both participants held the cube together, and participant 10 occasionally stroked Birdbox, as if it were a pet.

These bodily interactions appear to develop as participants became more comfortable. In session A, participants initially (in the visual-haptic condition) held Birdbox as a cube—with no support to the bottom of the cube. In the following phases, participant 1 started to hold Birdbox as a small bird, supporting the base. Participant 2 would occasionally join the interaction and gently touch the cube, even when there was no haptic output. This holds similarities to Session F, as depicted in Figure 3.

However, not all bodily interactions were soft and gentle. Whilst exploring aggression levels of pigeons in the audio-haptic modality,

Figure 3: Stills from session F, showing how participant 11 and 12 interact with Birdbox for three different birds under noise pollution (pigeon, gull, and starling). The noise pollution was communicated through audio-visual output. From left to right: The left person holds Birdbox, the other participant then softly stroking the box, and the left person delicately holding Birdbox.

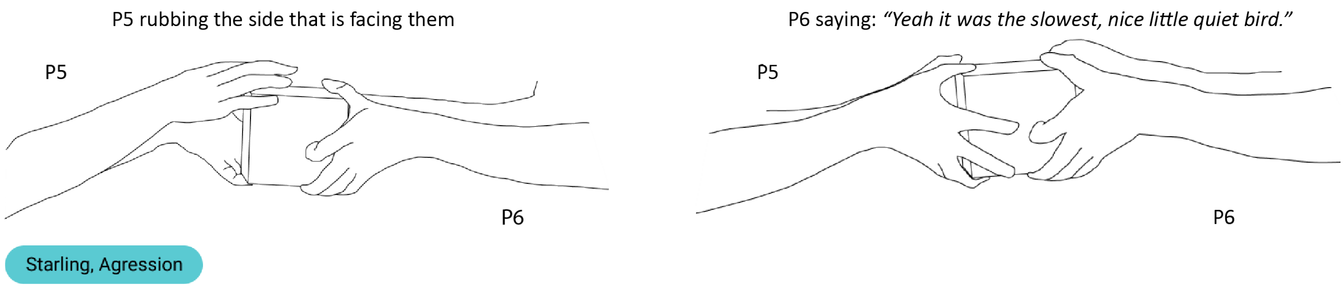

Figure 4: Illustration of participant 5 and 6 in session C experiencing the aggression data of starlings via audio-haptic feedback.

Figure 5: Left: Participant 9 and 10 in session E holding Birdbox together, experiencing noise pollution from starlings through visual-haptic output. P9 holds Birdbox, whilst P10 strokes it. Right: P1 angrily points their finger at Birdbox, when experiencing pigeons' aggression levels audio-visually.

participant 1 (session A) angrily pointed at Birdbox (figure 5, right). This reaction was triggered by a previous negative experience with pigeons. During the audio modalities, two sessions evoked further bodily interactions. In session B, participants started dancing to high levels of audio output, and in session F, participant 10 tapped Birdbox synchronous to the audio output rhythm, possibly in an attempt to understand the rhythm more.

6 DISCUSSION

Since participants showed clear preferences for modality, experience, and metaphorical mappings, we discuss future implications for multisensory data representations. Furthermore, we reflect on the bodily interactions triggered by Birdbox and discuss our limitations.

6.1 Modality and Mapping: User Experience over Accuracy

Study participants expressed a preference for the haptic modality over other modalities due to the bodily experience it gave and the way it grabbed attention. Moreover, slow vibrational output was often interpreted as breathing or a heartbeat, adding to the impression that Birdbox was a living entity. Given birds are living creatures, the impression of holding something that is alive could have added to the data experience. Moreover, audio output was not preferred, as it was considered to be too 'technical' and binary (cf. [17])—the opposite of something organic and living. This suggests that participants preferred a modality that conveys 'aliveness', with haptic output being best suited.

Furthermore, participants came up with their own mappings between representational modalities and data despite being given clear instructions. This is similar to observations in previous work, for instance commenting on haptic output to feel 'like a heartbeat' [17], or compared sound output to a siren and buzzing bees [16]. Our participants associated haptic output with aggression, and imagined additional (non-intended) mappings between haptic output and the size of birds, or between audio output and speed or activity levels. These are all metaphorical mappings [56], which indicates that some modalities inherently afford certain mappings. Previous work on crossmodal representations and correspondence has highlighted *congruence* [23, 33]: *"an intuitive match or harmony between the designs of feedback from different modalities"* [23]. Our findings provide further support for this hypotheses of modality-data congruence. Future research should explore this in more detail (e.g. what is the role of different data sources, contexts, which data is best represented through which modality, etc.).

Overall, participants did not like the visual output, possibly because its mapping was deemed hard to decipher. However, participants also stated that people are very used to visual output, so it does not stand out enough. Similarly, in the work of Hogan et al. visual output was described as 'familiar' [16]. Whereas previous research indicated that auditory and haptic cues can be used to highlight visual features [10, 11], our findings reveal that audio and haptic output overshadowed the visual. This indicates both promise and caution for crossmodal data representations. On the one hand, use of haptic and auditory modalities could prevent over-familiarity, thereby reducing post-hoc rationalisation, and potentially fostering deeper connections to the data [51]. On the other hand, these may overshadow the visual (thus effectively be perceived as mono-modal). Designers of multisensory/crossmodal representations need to be aware of this. Hogan et al. advise that representational modalities should have equal intensity [18]. Our study adds to this indication of a potential for synchronising haptic and audio output, so that modalities enhance each other. Future studies should explore whether this enhances clarity and experience of crossmodal data representations.

Lastly, the data mappings used in our study were relatively simple. Analysis shows that participants looked for more complex experiences and intricate data mappings (section 5.1.4). Future studies could explore which complexities (e.g. rhythms and patterns) of sensory patterns are interesting, yet legible and not challenging for users.

6.2 Bodily Reactions to Data

For the author team, most striking were the observed bodily interactions with Birdbox. We assume that the form factor and resulting affordances (designed to be comfortably held in one hand) supported these. Observed behaviors confirm and add to participants experiencing Birdbox as a living entity. Birdbox was held as if it was a small, delicate bird, stroked and softly petted, or pointed at angrily. These behaviors seem rather unusual for data visualisations. Previous work [17, 18, 52, 53] already indicated that physicalisations and data representations that go beyond the visual are experienced as something alive, and that emotions play a role in their perception. Our work adds to this, showing that people not only experience a multisensory data representation as alive, but also respond emotionally to it via bodily interactions, either positive (e.g. stroking) or negative (e.g. aggressively pointing at it).

Moreover, Birdbox's audio output appeared to affect participants, who started dancing or tapping to the output beat. Currently, *sonification* [30] is still a research area with lots of open questions [15]. Considering the bodily interactions triggered by our simple audio output, we believe it worthwhile to further explore how people experience auditory data representations, the interactions invited, and how this influences how people make sense of data.

To our knowledge, our work is one of the first to reveal these rich interactions with a handheld, multisensory data representation. Other studies should expand on this, using other data sets, designs, and modalities. Although the role of the human body has been explored and embraced in HCI (e.g. [24, 26, 31, 34]), it has not received a lot of attention yet in research concerning data representations—with a few exceptions, e.g. [16, 28, 43, 44]. We agree with Hogan et al. [16] that it is time to start exploring the role of the human body in our interactions with data and data representations.

6.3 Limitations to Our Study

As a limitation to our study we note that Birdbox was not fully-functional, with some output actuated by a researcher. This could have resulted in a slight delay of audio and haptic feedback and thus influence user experience. Also, the data signals were not validated beforehand. Across all modalities, participants were unable to distinguish the four data levels; most could only distinguish three. In interviews, it became clear that 'reading' levels from the blinking LEDs frequency (visual signal) was too difficult. This could be improved in future studies by prior testing and redesign of signal levels to ensure these are easily distinguishable (although there might be intrinsic limitations to human perception, if only basic signals, and not rhythms are utilized).

The exact design of the signals can also impact users' preferences for signals and their interpretation. For instance, vibration design can influence perceived pleasantness or urgency [45] (as we used a consumer device that emits vibration, this is designed to be sufficiently pleasant). However, participant's might have had difficulty 'reading' signals in unfamiliar modalities. People are likely not used to interpreting blinking lights, whereas they might feel more comfortable interpreting beeping frequency and vibration signals, as these are used in alarms (and timers) and mobile phones respectively. At the same time, novelty effects might influence preferences for the haptic modality. These kinds of influences are unavoidable in user studies that assess under-utilised modalities, and could only be mitigated through prior long-term exposure to such representational modalities. Nevertheless, other studies have found similar preferences for haptic representations due to it being a more embodied experience [16, 17].

Moreover, the data set was explored always in the same order, to provide consistency in what participants learn about the birds over time. But the order might influence reactions to modalities; in particular if some modality-data combinations are perceived as a better mapping than others. Lastly, our participants were all students. Although their age and cultural background varied, a larger and more diverse participant sample is recommended.

7 CONCLUSION

We presented a study of Birdbox, a multisensory, crossmodal data representation which conveys data on birds considered an urban pest. Twelve participants in pairs experienced data regarding droppings, noise pollution, and aggression levels of six bird species. The data was communicated via audio-haptic, haptic-visual, or audio-visual output. Participants interacted with Birdbox three times, to experience all modality combinations. Analysis focuses on how people experience crossmodal, multisensory data representations.

Our findings show that haptic output was preferred, as it drew attention and triggered bodily sensations. Participants liked the audio-haptic combination, as modalities amplified each other, easing understanding of the data. They further tended come up with their own mappings, linking haptic output to aggression levels and audio to speed. Our research thus indicates that there might be a semantic congruence (or metaphoric connections) between modalities and data items. Furthermore, participants often described Birdbox as a living entity, comparing it to a small pet or beating heart. This was also reflected in their bodily interactions, holding Birdbox as if it was a small bird, stroke, or angrily point at it. Especially for haptic output, our work indicates that it can enhance engagement with data and can foster the idea of the artefact being a living entity, which facilitates bodily interactions with the data representation.

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