Shapes of Emotion: Mapping the Intersection of Visual and Tactile Modalities with Emotions

Oliver Cairns
University of Bristol
lf21817@bristol.ac.uk

Thomas Burt-Gray
University of Bristol
lu21864@bristol.ac.uk

Mekyle Faisal Alam
University of Bristol
qo20407@bristol.ac.uk

Yousuf Alawadhi
University of Bristol
nt19027@bristol.ac.uk

Badr Makhdoom
University of Bristol
ai20192@bristol.ac.uk

ABSTRACT
UPDATED—September 9, 2024. This paper explores the relationship between the associated emotions of visual and tactile modalities in the form of three-dimensional (3D) shapes. By utilising our interactive exhibit - “Shapes of Emotion" - we take a gamified approach, aimed to investigate the correspondences between 3D shapes and a range of clearly separable emotions. Our results contribute to a deeper understanding of mappings between physical characteristics of 3D shapes and emotional outcomes, validating pre-existing research. Our findings identify consistent emotional correlations with related studies and some unexpected divergences resulting from specific shapes. Furthermore, the evaluation of our results highlights the complexity of the multi-sensory-emotion relationship, and suggests that tactile and visual perceptions of shapes significantly influence emotional responses. Our study validates existing theories of cross-modal correspondences, broadens the understanding how sensory modalities affect emotional outcomes, and introduces new directions for research to design emotionally resonant interactive experiences.

Author Keywords
Human-Computer Interaction(HCI); Cross-modal correspondences; Sensory modalities; Emotional perception; 3D shapes; Visual and tactile perceptions; “Bouba" and “Kiki" effect; Interactive exhibit

INTRODUCTION
In the vast field of Human-Computer Interaction (HCI), there is a growing interest in exploring cross-modal correspondences. These are an interesting phenomena where one feature from one sensory modality is intuitively associated with a characteristic from another sensory modality [20][22]. Sensory modalities refer to the different types of sensory input that the human brain uses to process information, these include: vision, touch, scent and sound, among others [4]. Building upon the understanding of cross-modal correspondences, it is crucial to consider the use of different senses, and their role in influencing our emotional perception through physical objects. This raises the question, are our emotional responses triggered by cross-modal correspondences, specifically touch and vision? This paper outlines an interactive exhibit that explores this relationship by attempting to correlate the visual and tactile perceptions of 3D shapes to certain emotional responses.

Current research has provided empirical evidence on such cross-modalities. For example, this can be seen in the well-documented “Bouba" and “Kiki" effect. This has been used in word-shape associations [8], where an inherent link between sound symbolism, and visual form is established [21]. As well as this, the “Kiki" and “Bouba" effect has also been demonstrated across different cultures [3] and ages [11][18] . Other research explores the relationship between 3D shapes, multiple sensory modalities, and their relationship with perceived emotions [13] [10]. However, not only do these studies confine themselves to only three categories of emotional responses, they also limit themselves in the number of participants, and their demographic. This project seeks to address these limitations by mapping three-dimensional shapes to six distinct emotions, thus streamlining the scope of emotional classification associated with 3D shapes. By enabling widespread participation, the exhibit aims to lay a foundational basis for further scholarly inquiry.

To address these limitations, we created “Shapes of Emotion", an interactive exhibit that aims to intrigue participants to learn about how they perceive their emotions as shapes. In our exhibit, two users are prompted by an emotion, selecting from multiple shapes in order to find potential mappings influencing their decisions. By doing this, each user can see if their shapes relate to both their partners emotional responses, and all previous users who have interacted with the exhibit. By encouraging the participation of people through public involvement, we were able to collect a wider population sample for more areas of study. This engagement model could improve comprehension of cross-modal correspondences with a more defined range of human emotions.

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This exhibit would ideally reside in a museum setting, where two participants would engage with the device, and see the direct comparisons between their perceptions. In doing this, the exhibit aimed to close the gap between the research of cross-modal correspondences and emotions, that is confined to academic journals, to the general public. Resulting in an educational experience that enlightens users' knowledge about this topic and our area of research.

The engaging nature of our exhibit facilitated mass collection of quantitative data, we used the gathered data to identify tangible associations between 3D shapes and emotions. Our results supported existing correspondences and suggested areas where new mappings could be established.

Essentially, “Shapes of Emotion" provides a framework that enables the exploration of this complicated relationship. This aims to allow future work to refine the choice of shapes and emotions, incorporating other multi-sensory modalities that may affect users decisions. A better understanding of this relationship could provide a deeper insight on what factors of HCI design can elicits the desired emotional responses from users.

BACKGROUND

As mentioned, The term cross-modal correspondence refers to uncovering consistent mappings between multiple stimuli from different sensory domains [20][22]. By analysing the relationship between seemingly unrelated modalities, a common feature can be uncovered. This can result in consistent mappings between certain qualities that highlight this correlation. Multi-sensory interactions employ different sensory modalities to outline what factors may influence these cross-modal mappings, helping us uncover these relationships [4]. This section outlines the related studies surrounding cross-modal, multi-sensory interactions, along with the motivation behind our exhibit, addressing the current gap in research it aimed to fill.

CROSS-MODAL CORRESPONDENCES

In the field of HCI, the study of cross-modal correspondences through the use of multiple sensory modalities has been researched in a variety of ways. Many studies regarding the relationship between different modalities have contributed to a number of different domains. For example, research surrounding the relationship between music, colors, and emotions has helped uncover distinct evidence showing that music-to-color mappings are mediated by emotional states. The research found robust mappings between expressive faces and colors, along with music and expressive faces, which could be used in theatrical performances and musical events to evoke certain emotions [19]. Another study explored how cross-modal correspondence mappings can increase the efficiency of wearable augmentation devices for movement and sensory purposes. They talk about how multi-sensory modalities, specifically haptic and visual, can prove useful for motor control functionality, and in discerning the position of objects. Furthermore, the researchers outlined how the spontaneous nature of these correspondences could be exploited to reduce the cognitive burden of additional sensory inputs for users [20]. Another

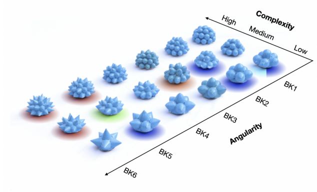

Figure 1. 3D printed tangible objects with varying levels of complexity and angularity as illustrated in Figure 1 on page 1 of work by Metatla, Oussama and Maggioni, Emanuela and Cullen, Clare and Obrist, Marianna [13]

interesting study used multi-sensory modalities to explore how Brain-Computer-Interfaces (BCI) can give us a better understanding of the transient changes in the brain. They designed two experiments exploring how cross-modal correspondences between haptic touch, visual, and auditory stimuli affect participants reaction time. By exploring multiple modalities to test reaction time, they were able to discover the potential for integrating haptic feedback to enhance user experience and information transfer rate (ITF) [2]. As mentioned, cross-modal correspondences have been explored in a number of applications and domains, ranging from medicine, to entertainment [2][19]. This field of study enables researchers to explore how cross-modal interactions can reveal useful mappings for a huge variety of use cases.

EMOTIONS AND SHAPES

Current work surrounding emotions and shapes has been done to explore the potential of creating more emotionally resonant design practices in HCI. For instance, Metalta et al utilised 3D reconstructions of the popular “Kiki" and “Bouba" shapes, along with the sensory modalities of scent and touch. They did this to explore how their findings could influence more inclusive interactive multi-sensory technologies within children. They found that “Kiki" shapes were associated with arousing emotins and “Bouba" with more calm emotions[13]. Related research, designed a taxonomy of mappings between how the physical form of shapes are affected by emotions. They aimed to see how emotion affected different modalities like vision and touch, to define consistent mappings between them. Their research provided valuable insights on how non-professional designers perceived their emotions as physical objects, in order to understand what HCI design factors could be integrated to provoke certain emotions [12]. Another study by Metalta et al, explored the use of vision and touch with emotions, to help improve the design of emotionally resonant, interactive technologies. They translated the popular “Bouba" and “Kiki" shapes into 18 3D objects, adopting a range of colours, featuring three levels of protruding frequency (complexity), and six levels of angularity. These shapes can be seen in figure 1 . They categorized their emotions into pleasure, arousal, and dominance, conducting separate studies to see how the shapes revealed more intricate associations between vision, touch and emotion. Overall, their results aligned with previous research surrounding the“Kiki" and “Bouba" shapes, along with certain results exposing more complex relationships between their cross-modal stimuli and defined categories of emotion [10].

MULTI-SENSORY INTERACTIONS

Regarding multi-sensory interactions, researchers have experimented with how technologies can integrate multiple forms of sensory stimuli to enhance user experience. One study identified how current digital communication strategies, such as text messengers, lack the emotional feedback users intend to convey through their messages. Their paper addresses this issue by proposing a system aimed at improving emotional connection in digital communication, known as *Touch*. Their primary mode of interaction, a wearable device, portrayed the user emotions through the multi-sensory means of light, vibration, and tactile feedback. Their experimental results showed that users who were told to use the device, were 30% more accurate in guessing the given emotion, compared to those who were told to use their integrated mobile application [1]. Another study explored the use of an innovative haptic technology system. Their system was able to use tactile stimulation in mid-air to convey emotions to the participants. After testing their implementation, the findings demonstrated a non-arbitrary mapping of emotions through haptic stimuli. This highlights the importance of touch as a sensory modality, illuminating the potential for tactile feedback to serve as a medium for emotional communication [17]. Multi-sensory interactions have also been used to explore the relationship between multi-sensory processes affecting brain plasticity. Their research aimed to provide a potential outlook on the clinical applications of multi-sensory testing on the brain. They explored the use of multi-sensory processing in early development and its application for victims rehabilitating from medical issues - like strokes. Their findings show that musical approaches, using sound and touch, aided stroke victims in rehabilitating their cognitive processes after an accident. They also found insights on the mechanisms that affect neuroplasticity in the brain, finding that healthy cognitive aging was associated with multi-sensory training methods. The research surrounding these interactions shows a variety of use cases, from using different sensory modalities, like touch and feel to convey emotions, to incorporating them into methods to aid in rehabilitation practices.[1][23].

MOTIVATION BEHIND SHAPES AND EMOTION

> A better understanding of emotional communication will be crucial in creating new, “affective” HCI interfaces and immersive media experiences [16]

Current research explores how cross-modal multi-sensory interactions can benefit a range of domains, from influencing emotionally resonant design in HCI, to providing a framework for victims of stroke and terminal illnesses like Parkinson’s disease [12][23]. Other research has aimed to study the relationship between shapes and emotion, exploring how multiple-sensory modalities, like touch, smell and vision affect the humans perception of certain emotions [13][12][10]. Though this research has explored the relationship between shapes and emotion, they have always incorporated other sensory modalities acting as tertiary, or quaternary factors that can affect users emotions. None of these studies have been able to clearly outline shapes that have direct mappings to specific, separable emotions. Metalta et al, studied the effect of different variations of the “Kiki" and “Bouba" shapes, but limited their emotional response to only 3 categories. By doing this, they enabled each shape to be associated with a certain mapping, but did not specifically gain explicit correlations between one shape and one emotion. As well as that, previous research has focused on certain demographics, like children or non-professional designers [13][10][12]. Foundational research regarding this field has shown that “Kiki" is strongly associated with more intense/harsh emotions, while “Bouba" is more typically associated with calmer/softer emotions [21]. Our study intends to build upon this current research which explores the emotional associations of shape, through the use of cross-modal, multi-sensory interaction of vision and touch. Our exhibit, “Shapes of Emotion" targeted the general public, aiming to further develop our understanding of one to one mappings between shapes and easily identifiable emotions, like the ones associated with “Kiki" and “Bouba". By designing the exhibit to cater to the general population, we aimed to gather a significant amount of data regarding these mappings, and accomplish a more in-depth understanding of emotional perception to help the development of future HCI design.

DESIGN

In our design process we outlined two aims: To create an exhibit that allows the investigation of the emotional perception of touch-visual correspondences through public participation, and to pick the shapes that were to be used for the exhibit.

This chapter outlines the different stages of our implementation, explaining our design choices and how we overcame challenges to encompass the exhibit within the research aims.

STAGE 1 - INITIAL DESIGN

During the initial stage of our design process, we produced a mock-up representing the final exhibit to understand how to make our design as intuitive as possible, for the general public. We started with a simple sketch outlining the appearance and functionality of the exhibit.

Initial Design

The initial design (Fig. 2) shows our first mock-up, an exhibit where users place shapes into separate boxes, each labelled with separate emotions.

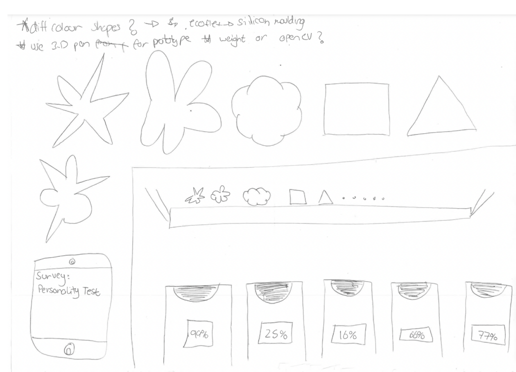

Figure 2. Sketch of first device setup.

This large selection of boxes aimed to attract a multitude of museum visitors, allowing multiple participants to interact with the exhibit at one time. Because of this, we chose this setup to streamline the process of interaction.

To complement this design, we added a shelf for each shape to sit on, allowing users to clearly see the variety of options they could choose from while waiting for their turn. We also displayed each emotion on an LCD (Liquid-crystal display) screen, along with statistics regarding how many other participants chose the same shape for that specific emotion. We did this to provide an easy way for participants to gain statistical insights on their choices, maintaining strong engagement throughout the exhibit. We also thought of implementing a personality test in the form of a mobile application to further engage users and find potential mappings between shapes, emotions and personalities. After completing the test and engaging with the exhibit, users would be categorized with other people who chose similar shapes, identifying correlations between their personalities and their decisions.

Design Insights

Through analysing our first design, we noticed that having a larger set-up, with a box for each emotion, was not ideal for a museum setting. This was because it was lacking sufficient versatility to be placed in public settings with ease, and would require the addition of boxes whenever new emotions were to be introduced, hindering the scalability of the device. Additionally, we thought the exhibit would not feel engaging enough in this structure and realized certain technical limitations. We found that the LCD screen provided to us would be too small to sufficiently convey the required information in a format that would read comfortably. In terms of the personality test, we found that separating users into different personalities would exceed the time constraints of the project and stray from the original aims of our research. We also realized that finding mappings between the shapes, emotions and personalities would be too complex to implement accurately. Despite flaws in this original design, this stage shed light to a number of challenges that we have addressed in the next section of our design phase.

STAGE 2 - FINAL EXHIBIT DESIGN

To address the shortcomings of the first design, we redesigned the physical configuration of the exhibit. By considering the technological limitations of creating the device with 6 boxes, we decided to implement one box for all emotions. By utilising an external monitor to prompt users with each emotion, we reduced the magnitude and technical complexity of the device, negating the need for individual LCD screens. Additionally, we discarded the personality test and mobile application, considering the time constraints of our project, the additional complexity would not have been feasible to implement. Instead of this we opted to display relevant statistical results through the external monitor instead, allowing users to see how their choices compared with other participants. Our next design (Fig 3) details our new approach taken to create this device.

We opted to incorporate gamification principles to encourage more user participation, addressing the lack of engagement in the first mock-up. By editing the design to involve two users simultaneously, separated by a privacy screen, we aimed to prevent participants from seeing each others choices. This incorporated the gamification principles of social interaction [7]. We did this to encourage discussion and promotes reflective insights on our research. This helps participants understand our research goals in a digestible manner, as proving or disproving the existence of the cross-modal mappings between shapes and emotions can be seen at a one-to-one scale with their partner [6]. Overall, by incorporating multiple participants, gamification principles, and statistical insights on users choices, we have aimed to make the exhibit more engaging to the general public to garner more results.

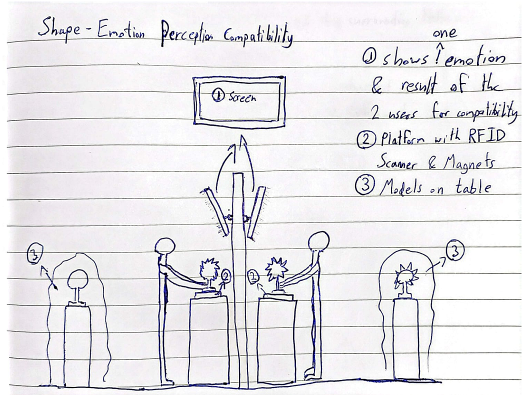

Figure 3. Sketch of second device setup

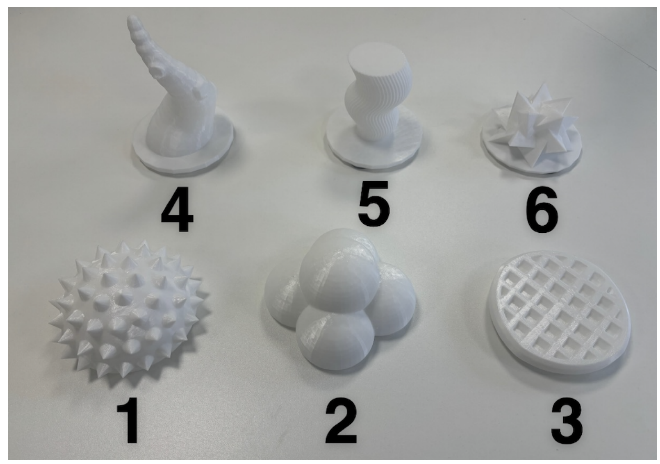

Figure 4. Indices of 3D Shapes

STAGE 3 - SHAPE DESIGN

After finalising the design of our exhibit, we focused on choosing the emotions and shapes that would be used for our research. To further understand potential cross-modal correspondences between 3D shapes and emotions, we carried out two data gathering surveys to understand what kind of shapes evoked certain emotions from the public. The results of these studies determined what shapes were eventually used for the final exhibit.

DATA GATHERING SURVEYS

To chose the emotions for our final exhibit we decided to use the six, most easily identifiable emotions, which were adopted from previous research. The emotions were: Happiness, Sadness, Fear, Disgust, Anger and Surprise[9]. This was done to maintain clarity between potential mappings of each shape to distinctly separable emotions.

Each survey contained a number of different shapes, asking participants to identify what emotion they felt from each one. To avoid colour bias, we selected shapes that maintained a black and white profile. Our first survey utilised traditional “Kiki" and “Bouba" models, along with a selection of randomised “Bouba" and “Kiki" like shapes, presenting each one in a two dimensional format. After collecting a total of 84 responses from the first survey, our results showed that the exact render of “Kiki" and “Bouba" , were mostly associated with similar results from previous research [13, 10]. “Bouba", along with the other “Bouba"-like shapes, were mapped to the emotions of happiness and sadness. The “Kiki"-like shapes mostly received feelings of anger and fear, as expected. Interestingly, the exact render of “Kiki" was associated with the feeling of surprise, rather than our expected outcome of anger. Overall, the survey was successful in identifying which kinds of shapes evoked certain emotions, with four of them being chosen to be used in the second survey, in order to verify their results.

We refined our second survey with design suggestions from study 1’s participants. We added two new options, an “other" field and “neutral" field, for those shapes which did not evoke any of the presented emotions, or any emotion at all. We adopted four shapes from study 1, incorporating six new shapes to introduce a new variety of options, as suggested from participant feedback. In order to avoid colour bias in our final exhibit, we also asked participants what color represented a neutral state. As a final design improvement we presented 3D renditions of each shape, as this was a more accurate representation of the shapes used in the final exhibit.

After launching survey 2, we collected responses from a total of 87 participants. Regarding the colour of the neutral state which would be used in the final implementation of our design, almost 40% of participants chose white. We expected similar results for the four shapes carried over from survey 1, but understood that the new 3D appearance of these shapes may change participants choices. Validating this assumption, almost all of the shapes had different results than the first survey. Surprisingly, “Bouba" (shape 2) saw a majority of participants choose neutral as their option. We suspected some bias was involved with this, as the colour of “Bouba" was white, and this question directly followed from the one regarding the colour of a neutral state. “Kiki" (shape 6) aligned well with results from previous research, as most participants chose angry, commonly associated with harsh emotions [13]. Shape 4 maintained similar results, relating to the emotions of disgust, fear and surprise, while shape 5, saw the most change from the first survey. We found that the emotions of sadness and disgust changed to the emotion of happiness.

After carrying out the final study, we filtered out shapes with a high variation of emotions, and those which had a high volume of neutral responses. Following this, we settled on six shapes for the final exhibit, four of these (shape 2, shape 4, shape 1, shape 6) were carried over from the first survey, with two new ones (shape 3 and shape 5) that showed significant preference to certain emotions (fear and happiness) in the second survey. The final choice of shapes can be seen in figure 4.

DEVICE IMPLEMENTATION

This chapter outlines the technical processes that were done to create “Shapes of Emotions". Here we explain the material used to create our shapes, how the exhibit was built, and the technicalities behind this.

Shape Implementation

We wanted to use material that would not influence the choice of shape through texture, as we only wanted users to focus on the dimension of each shape as their deciding factor. To do this, we used 3D printed models for the final shapes, experimenting with different materials, to choose one that did not evoke any texture bias. We originally printed test shapes with polylactic acid (PLA), which came out to be quite rigid and brittle. This material also caused frequent irregularities in the models, unexpectedly changing the texture of the shapes due to printing flaws. Given that our research does not aim to include the aspect of the material’s texture into the participants decisions, we decided against PLA due to the unreliability of the material. Because of this, we decided to print our final shapes with thermoplastic polyurethane (TPU), which was not only smoother, but more elastic, increasing the longevity of the models as they were expected to be handled frequently. As well as that, to improve user experience and enhance the sensory-modality of touch during the exhibit, we made our final shapes much larger than the test ones. Figure 5 shows the test model made with PLA, while figure 8 shows the final shapes made with TPU.

Figure 5. Test model made from polylactic acid (PLA)

Technical Implementation

The process in which our exhibit identified and registered data is outlined in figure 7. To facilitate shape detection on each of

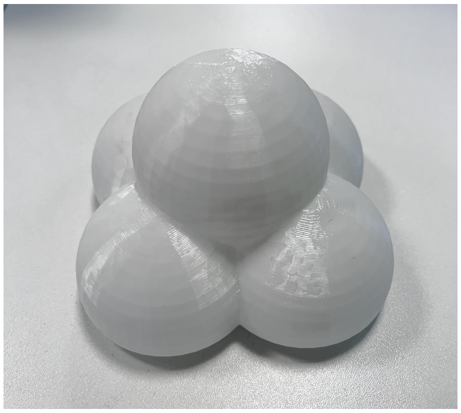

Figure 6. Final model made from TPU

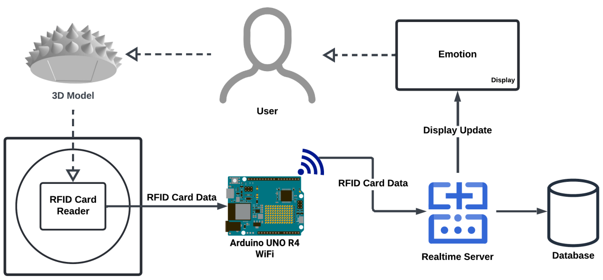

Figure 7. Final device architecture.

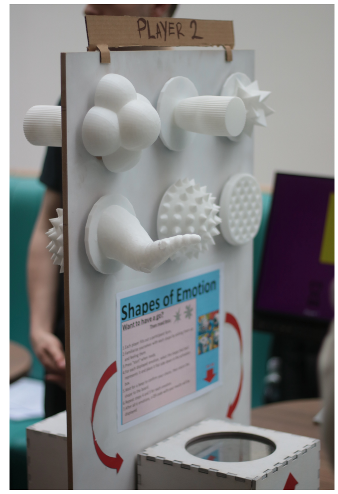

Figure 8. Final implementation of exhibit.

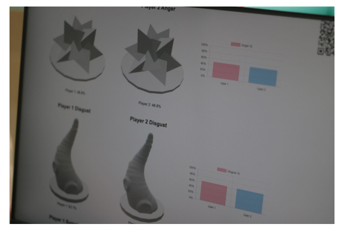

Figure 9. Exhibit display.

the platforms, each shape was embossed to hold RFID cards underneath. The platforms comprised of wooden boxes separated by a privacy screen, that were laser cut from plywood. Each platform had a circular cut out in the top, where we attached acrylic and one-way mirror film. We did this to guide the users on where to place their chosen shape. Each box contained an RFID reader module, magnets, a sound buzzer, and an Arduino UNO R4 WiFi. The RFID reader was fitted to the bottom of the thin acrylic sheet to allow shapes to be identified after being placed on the platform. After fitting the 3D models, platforms and privacy screen with magnets, we allowed the shapes to be intuitively transferred from the screen to the boxes with satisfying tactile feedback. By incorporating magnets into the platform, we also ensured that both the RFID reader, and RFID cards aligned properly after being placed. In doing this, we avoided cases where choices might not be registered due to slight misplacement's by the user.

The Arduino processes the data from the RFID reader and determined which shape was chosen by the user. After the shape was read, the Arduino sent data for the placed shape to our back end database, connected to a front end prompting a new emotion after each round. Each user was notified of their successful choice by both the sound of the buzzer inside their platform, and a check mark that appeared on the front end's external monitor. Once the back end registered both users' shapes, the monitor displayed each users choice, before moving on to the next emotion. The addition of magnets and buzzers, along with visual check marks on the display, was aimed to enhance the user experience, by ensuring immediate feedback, making interactions with the device intuitive and satisfying. The final implementation of "Shapes and Emotion" can be seen below in figure 8 and figure 9.

Critical Evaluation To gather insights on potential cross-modal mappings, we launched the exhibit for three days, collecting data from a total of 122 participants, a significant increase compared to other HCI studies in a similar domain [13][10][12]. This section outlines our results, highlighting potential mappings between our chosen shapes, and the six emotions. We also evaluate our design processes, identifying limitations in our exhibit, and the potential avenues for future work regarding this field of study.

RESULTS AND EVALUATION

The mappings from our exhibit launch are illustrated in figure 10. These will be evaluated in the following sub chapter. Following the exhibit, a survey collected responses from 88 participants, providing insight into the successes of the exhibit, whilst also highlighting limitations in our design. The survey questions can be seen outlined below:

- How intuitive did you find the exhibit?
- Did you find yourself confused during the experiment?
- Did you feel any bias towards picking a certain shape for an emotion? e.g. by picking a shape for one emotion affect future decision for other emotions?
- Did you find the exhibit engaging?

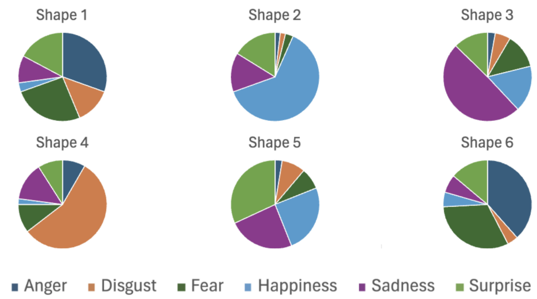

Figure 10. Distribution of Emotions Associated with Each 3D Shape

- Did you find participating with another person made the exhibit more intriguing?
- Did you find the results at the end insightful?
- Did you understand the objective of the exhibit?
- Were there any emotions which you felt should have been included?

Shapes

Many studies (e.g. [5] [15]) define correspondences using the criteria of 'exceeding chance level', we decided to adopted this methodology when evaluating our results to identify associations between shapes and emotions. Specifically, the observed associations must surpass what may be expected as random chance, bench-marked at 16.67%.

Analysing the emotional associations resulting from shape 2, our 3D reconstruction of "Bouba" 4, supports pre-existing studies that correspond calming emotional responses with "Bouba" [21]. We observed that 62.85% of participants associated shape 2 with happiness, with most remaining associations distributed amongst sadness and surprise (14.28% and 16.19%) respectively.

Similarly, shape 6, characterised by "Kiki" like features, produced results that concur with current work, that suggest this type of shape should elicit harsher emotional responses [**?**]. We witnessed most participants associated this shape with anger and fear (38.41% and 31.78%) whilst some associated this shape with surprise (13.90%).

Considering the emotional responses evoked from our "Bouba/ Kiki" representations, results collected from our gamified exhibit align with conclusions derived from pre-existing research [13]. By replicating these findings we legitimize our methodology, for collecting data through an educational and interactive experience.

Shape 1 gathers insight into the emotional responses elicited from a shape which possess characteristics of both "Bouba" and "Kiki". Our results depict a similar distribution of emotions to those of shape 6, with 30.46% of participants associating it with anger and 26.82% with fear. The only significant difference is a notable increase in disgust responses, from 3.97% in shape 6 to 13.24% in shape 1. The similarity between results of associated emotions corresponding to shape 1 and shape 6 indicate that the rounded features inherited from "Bouba" assume a more passive role compared to those from "Kiki", characterized by spikiness. Although the observed reduction in anger and fear selection can be attributed to the presence of "Bouba" features. These results uphold the relationship between the "Kiki" and "Bouba" features, demonstrating that the proportion of these characteristics influences the associated emotional responses, thus setting the stage for further exploration of shape-emotion dynamics in subsequent analyses.

Unlike the other shapes, shape 5 was not intended to have characterises with known emotional correspondences, it was selected through our survey process. By introducing features not represented in shapes 1,2 and 6 we attempted to widen the feature set already defined by "Kiki" and "Bouba". The emotional associations of shape 5 consisted of 25.00% of responses pertaining to happiness, 24.13% to sadness and 31.90% to surprise.

Upon further reflection, we note that whilst we did not intend to utilize "Kiki" and "Bouba" attributes, the curvature and cylindrical nature of shape 5 can be interpreted as a "Bouba" feature.

In comparison to all other results, as shown in figure 10, shape 5 is the only abstract shape that can portray a significant emotional response of surprise.

However, to understand the individual effect of the introduced features—vertically oriented, protruding nature, cylindrical shape, and grooved surface—on the emotional responses of shape 5, further research must be conducted.

For the next two shapes (shape 3 and shape 4) We acknowledge their resemblance to figurative entities. Upon this realization, we expected a bias in our results, where the physical properties of the shape would not necessarily be the predominant factor in perceiving an emotion.

Specifically, as shape 4 resembles a tentacle which, through a cultural perspective, frequently appears in literature and media as an attribute of monstrous or alien beings. This connection could evoke feelings of fear and discomfort, which can be attributed to the unfamiliar and often unpredictable movements of tentacled creatures[14]. Therefore, we expected a correspondence with emotions such as fear or disgust from shape 4.

In contrast, shape 3's likeness to a waffle is associated with the memory of a sweet or savoury treat, familiar to many. Because of this, we expected the bias to influence the emotional responses in favour of positive emotions, more specifically, happiness.

Whilst reviewing the statistical results for shape 4, our expectations were confirmed, demonstrating a clear 56.25% correspondence with disgust and all other emotional responses featuring less than 14% of responses each. Contradicting our initial beliefs, shape 3 was associated with sadness and happiness (56.25% and 16.90% respectively).

These findings suggest that the physical attributes perceived through cross-modal correspondences have significant input into our emotional perceptions despite external bias. This contradiction provides a foundation for exploring additional avenues of research into how cross-modal correspondences of shapes weighs up against bias from personal experiences.

Interactive Exhibit

One of our core objectives was to enhance the engagement of participants through gamifying the experience. We found that the average rating across 88 participants was 8.82/10 for engagement. The rating for featuring an intriguing design that encouraged participation was also high, at 8.80/10. Furthermore, in terms of the versatility and scalability of the design, we can refer to the ratings for intuitiveness and confusion, at 8.92/10 and 2.4/10 respectively. Moreover, the final implementation of the exhibit allowed for it to be setup in any location, with an external monitor to prompt emotion, as long as there was Wi-Fi present, as it needs a connection to record responses.

To evaluate the educational objective of this exhibit we consider our feedback, where participants scored our exhibit 8.44/10 in terms of understanding the objective of the exhibit. Similarly, participants scored the insightfulness of their results as 7.88/10. This meets our aim of closing the the gap between academic research on the relationship between cross-modal correspondences and emotions, and non-specialist users.

Generally, the exhibit can be considered a success in terms of accomplishing our engagement, educational goals and versatility objectives through our design choices, boasting a 4.82/5 average rating in overall experience, all of which contributed to the scale of our participant pool.

DISCUSSION

Limitations

It is important to note the limited demographic of the participants in both our initial surveys and exhibit. All the participants involved in testing our exhibit were affiliated with the same academic institution. By expanding the user pool to incorporate a wider range of age groups, cultural backgrounds and neurodiversity, the results would provide a more comprehensive understanding of the emotional perceptions through cross-modal correspondences.

Another limitation of our implemented exhibit is the bias introduced by figurative entities. As some cultures may not perceive the shapes in the same way as we outlined in the evaluation chapter, skewing the resulting conclusions away from sensory-based reactions, by adding cultural bias.

Whilst the insights that are outlined in the evaluation subchapter broaden the understanding of the emotional perceptions to the physical attributes of shapes, they do not quantify specific attributes to explore these mappings with higher granularity. By analysing variations of the shapes in a measurable aspect as depicted in figure 1, more conclusive findings can be found.

In addition, the texture of the shapes plays a valuable role in the tactile modality, different materials may evoke different tactile experiences and could potentially alter the perceived emotional association of a shape. This emphasizes the need to account for this factor, to fully understand touch's role in the perceiving emotions.

When evaluating the intuitiveness and general understanding of the exhibit concerning the research it aims to present, it is crucial to acknowledge our presence whilst users interacted with the exhibit. By answering questions and explaining our research aims, the intuitiveness of our exhibit in a standalone setting is misrepresented in our feedback.

Furthermore, emotional responses are not dichotomous, to achieve more accurate emotional perceptions of these cross-modal correspondences, a variable which quantifies the degree to which an emotion is perceived should be added to enhance the accuracy of our findings. Our current 6 emotions proved to be mostly representative of the emotional spectrum, although a large percentage of participants (17%) who provided feedback suggested that 'anxiety' should be added to the original 6 for a more comprehensive representation.

Future work

Future work should focus on enhancing the exhibit's ability to function independently and deploying it in various locations to engage a broader participant pool. Additionally, redeploying the exhibit with shapes that have quantifiable characteristics or varied textures and colours will enable more precise mappings.

Furthermore, future efforts could include giving users the option to select the intensity of their emotional perceptions, allowing for more nuanced data collection.

Conclusion

We proved that by using a gamified design, we increased engagement and educational outcomes of our exhibit. "Shapes of Emotion" reaped benefits from our design choices, as we featured more participants than any other HCI study in this domain, while also still finding correspondences consistent with previous emotional associations with "Bouba" and "Kiki" shapes. Furthermore, we introduced shapes consisting of new feature sets that potentially reveal new mappings. Exploration of this new avenue in research, offers comprehensive insights that could help guide the development of more complex and captivating multi-sensory experiences in the HCI domain.

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