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On the Perceptual Aesthetics of Interactive Objects

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ABSTRACT

In this paper we measured the aesthetics of interactive objects (IOs), which are three-dimensional physical artefacts that exhibit autonomous behaviour when handled.

The aim of the research was threefold: firstly, to investigate whether aesthetic preference for distinctive objects' structures emerges in compound stimulation; secondly, to explore whether there exists aesthetic preference for distinctive objects' behaviours; and lastly, to test whether there exists aesthetic preference for specific combinations of objects' structures and behaviours. The following variables were systematically manipulated: 1) IOs' contour (rounded vs. angular); 2) IOs' size (small vs. large); 3) IOs' surface texture (rough vs. smooth); and 4) IOs' behaviour (Lighting, Sounding, Vibrating, and Quiescent). Results show that behaviour was the dominant factor: it influenced aesthetics more than any other characteristic; Vibrating IOs were preferred over Lighting and Sounding IOs, supporting the importance of haptic processing in aesthetics. Results did not confirm the size and smoothness effects previously reported in vision and touch respectively, which suggests that for the aesthetics preference that emerges in isolated conditions may be different in compound stimulation. Finally, results corroborate the smooth curvature effect.

Keywords: Interactive Objects; Aesthetics; Structural Factors; Behavioural Factors; Design; Material; Perception.

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1. INTRODUCTION

In brand design, much attention is paid to the consumer experiences as a whole. In car manufacturing, for example, while it can be expected that the form and internal material are designed to covey a certain message (e.g. sport vs. family car), it may come as a surprise to non-experts that the sound of the door closing is also designed (Backer, 2013). The car door that closes with a deep sound is associated to quality (Parizet, Guyader & Nosulenko, 2008). Design for all the senses can go even further: Ford and Chrysler, to mention but a few, use a unique distinctive fragrance and hundreds of thousands of dollars were spent developing the distinct smell of the 1965 Silver Cloud Rolls Royce (Lindstrom, 2005). Another example is Singapore Airlines total branding, achieved via the orchestration of visual, olfactory, auditory and tactile elements acknowledged as contributing factors to the overall customer experience (Lindstorm, 2005).

Though empirical studies showed that aesthetics affect the perception of usability (Kurosu and Kashimura, 1995; Tractinsky et al., 2000), the value of aesthetics in the design of digital products has been largely ignored. The focus has been on functionalities and their usability, and interface design was valued only if it improved performance (Tractinsky et al., 2000). Nevertheless, in the past decade there has been increasing attention paid to the application of aesthetic theories (Bardzell, 2009), models and guidelines (Lim et al., 2007) for both the design of digital interfaces and of the tangible artefacts that users manipulate. Particularly, it has been argued that the concerns about designing the functionality and usability of digital products must be balanced with a focus on the aesthetics of their tangible form (Djajadiningrat et al., 2004). Technological advancements make it possible today to embed sensors into normal-looking objects and make those objects react to people (Kuniavsky, 2010). It is in this context that this research is positioned: it is key for the fields of human-computer interaction and tangible computing to be able to draw from evidence from psychology on how aesthetic experiences form in the interaction with different shapes and materials as well as with different behaviours an object can display. Design builds upon the evidence that, when multiple senses are stimulated at the same time, the resulting experience is richer and more immersive (Schifferstein & Spence, 2008). However, a question remains as to what is the contribution of each sense to the overall aesthetic experience. Psychology has attempted to answer this by studying each sense in isolation and looking at the aesthetic response to simple stimulus features; for example the study of shape in vision, or of the surface texture in touch. However, it is still unclear how each sense contributes to the overall aesthetics in a complex, multi-sensorial stimulation, e.g. how vision and touch interact to affect the overall aesthetic response. The current research moves in this direction: instead of studying each sense in isolation, it aims at identifying the contribution of each sense in a complex stimulation. This research builds upon Latto (1995)'s work on aesthetic primitives defined as a primary or fundamental "stimulus or property of a stimulus that is intrinsically interesting, even in the absence of narrative meaning, because it resonates with the mechanisms of the visual system processing it" (p. 68). This definition underlines the cause-effect relationship between the stimulus and the aesthetic response. Such aesthetic primitives, if they exist, may be hardwired in the cognitive system, and may have an evolutionary basis. However, empirical evidence that certain individual perceptual features are perceived to be aesthetically pleasant is not definitive. Studies on the aesthetics of colours, for example, found that dark shades of orange-browns and dark yellow-greens are strongly disliked relative to lighter, equally saturated oranges and yellows and relative to dark reds (Guilford & Smith 1959, Palmer & Schloss, 2010). However, it is difficult to consider the preference for these lighter colours as an aesthetic primitive as there are cross-cultural differences (e.g. Choungourian, 1968; Pastoureau, 2001); gender differences (e.g. Child et al.1968; Palmer & Schloss, 2010; 2011) and age differences (e.g. Franklin et al., 2009; Hurlbert & Ling, 2007).

Aesthetic preferences for objects' shapes have also been extensively examined. Golden ratio, complexity, symmetry, and size, for example, have been suggested as potential simple aspects of the stimuli that can make objects pleasant. The 'golden ratio' is obtained by dividing a line into two parts so that the proportion of the entire line to the longer segment is equal to the proportion of the longer segment to the shorter segment. When this proportion characterizes, for example, the ratio between the sides of a rectangle, it defines a rectangle that should be more pleasant than any other possible rectangles. Fechner (1871), who initially proposed the basic behavioural methods to study aesthetics in the 19th century, provided the first evidence for this supposed preference. However, the golden ratio as an aesthetic primitive has been questioned as many studies showed that in certain conditions the golden ratio is not preferred over other geometries (see, for example, Höge, 1997; Bruno, Gabriele, Tasso & Bertamini, 2014; McManus & Weatherby, 1997; McManus, Cook & Hunt, 2010; McManus & Wu, 2013; and van Schaik & Ling, 2003; 2006).

Birkhoff (1933) has proposed simplicity as an aesthetic preference. By studying polygons, the author suggested that aesthetics increases with the number of ordered elements (such as equal sides, equal angles, etc.) and decreases with complexity (number of sides, unequal sides, unequal angles, etc.). Furthermore, when complexity is kept constant, configurations that are more symmetrical should be preferred (Garner & Clement, 1963). However, the role of both simplicity and symmetry in aesthetics has been questioned. Boselie & Leeuwenberg (1985) and Eysenck & Castle (1971) suggested that the relation between simplicity and aesthetics of polygons is not linear, and that an intermediate level of complexity of about ten sides might be favoured over lower or higher number of sides. In addition, Berlyne (1971) showed that the aesthetics of complex stimuli increases with the duration of exposure, whilst duration of exposure reduces the aesthetics of simpler stimuli. The effectiveness of symmetry as an aesthetic feature has also been questioned, for example, by Jacobson & Höfel (2002) who found relevant individual differences with some participants consistently judging asymmetric shapes aesthetically more pleasant. This is particularly true of complex stimuli such as human faces: perfectly symmetric faces can be considered less attractive than slightly asymmetric ones (Swaddle & Guthill, 1995).

Another stimulus feature that has been suggested to affect aesthetics is size. According to Silvera, Josephs, & Giesler (2002), when everything else is kept constant, we tend to prefer larger pictorial stimuli than smaller ones. This result conflicts with Jackson & Ervin (1992) and with Langlois, Roggman & Reiser-Danner (1990), who found that very tall men or very big eyes are not aesthetically pleasant. Silvera, Josephs & Giesler (2002) therefore suggested that the simple rule "bigger is better" might be true only for abstract figures, but does not apply to human features; thus excluding that stimuli size, per se, can be an aesthetic primitive.

There is robust empirical evidence that smooth, curved contours make objects aesthetically pleasant; this phenomenon has been defined the “smooth curvature effect” (Bertamini, Palumbo, Gheorghes & Galatsidas, 2015). These findings confirm Hogarth’s analysis (1753) of curved lines as an expression of grace and beauty. The preference for curvature has been confirmed by studies in design and neurology. In design, Leder & Carbon (2005) and Leder, Tino & Bar (2011) found a strong preference for smooth curvilinear car interiors over angular interiors. Neuroscientists have shown that the smooth curvature effect has a neural basis: using an fMRI technique, Vartanian et al. (2013) found that when participants were presented with curvilinear stimuli there was an activation of the anterior cingulate cortex, which is typically involved in the processing of emotional aspects of stimuli.

Despite the large amount of data corroborating the preference for smooth curvatures, there is still a lack of agreement amongst researchers. Firstly, Carbon (2010) suggested that preferences for curved objects could also be modulated by fashion, trends or Zeitgeist effects. The author noticed that the preference for cars with a smooth exterior design has an inverted-U shaped relationship over the years. In the 1960s, people preferred cars with sharper edges, whilst in previous and later years people preferred more curved shapes. Secondly, even acknowledging that there exists a preference for smooth curvatures, it is still under debate whether this preference is a secondary effect of disliking angular shapes (the "threat hypothesis", see Bar & Neta, 2006; 2007) or if it is a genuine preference for curvature (Palumbo, Ruta & Bertamini, 2015).

The aforementioned aesthetic effects have been extensively studied only in vision and it is still not clear if they extend to other human senses. In fact, not many aesthetically pleasant perceptual features have been found when studying other senses [1]. Carbon & Jakesch (2013) noted that in most areas of perceptual sciences the effort to understand different phenomena is dominated by research on visual dimensions. This also holds true for empirical aesthetics: most aesthetic theories are consequently inspired by visual phenomena and are only tested with regard to visual effects. As an exception, some research on aesthetic preference regarding the sense of touch has been conducted. Ekman, Hosman & Lindstrom (1965) suggested that "smoothness" affects touch perception. Among other tasks, participants in their study were requested to provide preference judgements on surface textures presenting seven levels of smoothness, ranging from smooth paper to coarse sandpaper. The authors found an almost perfect linear relationship between smoothness and touch preference: the

It is worth mentioning that there are other supposed aesthetic features such as saliency (Taylor & Fiske, 1978) and familiarity (Whittlesea, 1993). However, these cannot be considered purely perceptual features as they involve different cognitive factors such as memory and attention.

smoother the paper, the higher was the preference. This preference has been questioned by successive research. Rowell & Ungar (2003a;b) and Jehoel, Ungar, Mccallum, & Rowell (2005) obtained the opposite result: by using different materials (paper, plastic and aluminium), authors found that participants find aesthetically more pleasant touching rougher substances over smoother ones.

To sum up, perceptual aesthetic preferences have tended to be tested for each sense in isolation and, even within such constricted research conditions there is no convincing evidence as yet that any of these preferences can be said to be a "primitive". In addition, most of the research on aesthetics has studied static stimuli and in over-simplified conditions. Specifically, studies on the effects of curvature or size have been conducted on flat 2D surfaces (either computer screens or on paper) overlooking the possible effect of manipulation (touch) on the overall judgement. In this regard, Carbon & Jakesch (2013) argued that a model to describe aesthetic responses to object perception must take into account more than one sense at a time. The authors discuss how things we see often invite us to touch, and that a product's success may be due to haptic and tactile features that may overpower, in terms of pleasure, other senses. This seems to suggest that perceptual aesthetics derives from a combination of factors related to the overall hedonic experience. In order to study aesthetic primitives, it is important to use stimuli that address more than one sense at a time, in what we define as 'compound stimulation'. In this way, aesthetic primitives may emerge from the analysis of the interactions among combinations of the different features.

In the current empirical study, we consider a case of compound stimulation that makes use of digital components to augment specific sensorial aspects of objects. We created a set of Interactive Objects (IOs) for handling that are capable of exhibiting different behaviours, and collected participants' responses to each of them. Advancements in digital technology allow for sensors and electronics that can be easily embedded within relatively small objects

(Kuniavsky, 2010). These sensors and actuators can make objects display different behaviours when a user interacts with them in a specific way. For example, by sensing when the object is picked up it is possible to make that object suddenly vibrate or light up.

Little research has been conducted thus far on aesthetics benefiting from the complexity of IOs. In particular, it is still unknown whether IOs' "behaviour" is an aesthetic feature by itself. In addition, it has not yet been investigated how contour type, size, and surface texture of IOs interact with their behaviour to affect perceived aesthetics.

The large-scale studies reported here examined participants' reactions when interacting with objects that display digitally enhanced behaviours. In this way, it was possible to study aesthetic preferences for complex objects whilst engaging multiple senses. The aim of this research was thus threefold: firstly, to investigate whether aesthetic preference for distinctive objects' structures emerges in compound stimulation; secondly, to explore whether there exists aesthetic preference for distinctive objects’ behaviours; and lastly, to test whether there exists aesthetic preference for specific combinations of objects' structures and behaviours.

The research is articulated in two main studies plus a control experiment adopting two different research methods. The first study utilised a qualitative methodology to identify the dimensions underpinning the aesthetic features of IOs; the second study and the control experiment systematically investigated how different combinations of structure and behaviour affect aesthetics in terms of the dimensions identified in the first study.

2. STUDY 1: AESTHETIC DIMENSIONS

The purpose of the first study was to identify the aesthetic dimensions to be measured in the second study. The need for this first step was motivated by the fact that no previous study in aesthetics has used three-dimensional objects assessed via multiple senses. It was unknown if and how existing measuring instruments (semantic differentials used in experimental aesthetics, e.g. Berlyne, 1971; Biaggio & Supplee, 1983) would be valid in a setting where complex objects stimulate multiple senses at the same time. In addition to structural factors, behavioural features (e.g. emitting light, vibrating or sounding) had to be taken into account. To this end, participants were asked to interact with a range of objects and to indicate which ones they liked or disliked. In order to ascertain the dimensions of aesthetics, participants were also asked to explain the reasons behind their likes or dislikes and then the dimensions were identified from their responses. Thus, the dimensions of aesthetics explored here were derived from our participants rather than any previous beliefs or biases of the researchers.

2.1 Method

2.1.1 Participants

A cross-section of participants was needed to guarantee the collection of a data set that was representative of the general population. Therefore, wide email calls across the hosting university, social media shout-outs, and flyers distributed in the street and at university Open Days (with prospective students and parents attending) inviting people to take part in the research. A USB memory stick was given to all participants as a token of gratitude. The data collection was done over several days in three different university buildings located in different parts of a northern city in the UK (Sheffield). Overall, 175 participants took part in the first study generating 350 written responses. The sample was varied with 98 females and 77 males with an age range of 18-66 years.

The study was carried out according to our institutional guidelines for ethical issues and in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained from all participants.

2.1.4 Apparatus and Stimuli

To achieve the project aims, a set of interactive objects (IOs) were specially created for the research, each of them mapping a specific combination of the variables that were to be systematically manipulated:

(1) IOs' contour: rounded vs. angular was implemented by generating spheres and cubes, respectively;

(2) IOs' size: small vs. large was implemented as being able to be held in one hand (but still large enough to contain the electronics, 7.5 cm) or needing two hands to handle (15 cm), respectively;

(3) IOs' surface texture: rough vs. smooth was implemented with the surface material of IOs being canvas fabric and plastic, respectively;

(4) IOs' behaviour:

- Emit a light: the object gently glows when picked up;
- Play a sound: the object buzzes when picked up;
- Vibrate: the object vibrates when picked up;
- Quiescent: the object does not display any behaviour when picked up (baseline condition).

Implementing all combinations of Contour, Size, Surface texture and Behaviour resulted in thirty-two unique objects which differed in at least one characteristic to all other objects. In this way, it was possible to control the effect of each variable independently from the others as well as measuring their interactions.

Table 1 here

Table 1. Characteristics of the interactive objects.

The behaviour was activated by a motion sensor that controlled either the LED (light), buzzer (sound), or motor (vibration) components. These electronic components were packed into a small plastic box and embedded within the object's shell (Fig. 1, bottom right), therefore, when the variable was the behaviour, the objects looked the same as the others and participants would not know what any one object would do before they picked it up. In other words, among the 32 objects, 8 groups of 4 looked the same and it was only after they were picked up that they produced the different behaviours (see the appendix 1 for an account on how the IOs were built).

To avoid potential confounding variables, simple behaviours were chosen. Furthermore, the different behaviours produced by the objects were triggered by the same user action - to pick up and hold. All the objects were inactive when stationary on a surface, and produced behaviour only when picked up.

Behaviours were implemented using an Arduino Mini board fitted with a motion sensor to detect the objects being picked up and put down (which switched the behaviour on and off), and an output of LED lights, buzzer, and motor vibration.

Behaviours were designed to occur as similarly as possible; all started when the object was picked up and stopped when put down. Light, sound and vibration were not continuous, but pulsating - giving a stronger impression of an active object. The vibration was created with a Pulse Width Modulator output that generated an almost inaudible sound (under 0.5 dbs. at a distance of 50cm) and therefore only the sense of touch was stimulated. The intensity range of the vibration motor was set between 0-255. Once the maximum intensity was reached, it dropped by 5 unit steps with 30 milliseconds delay in each drop. This loop continued until the object was put down by participants. The motion sensor would then detect that the object was in a static position and would switch off the behaviour. The light of the LED was set in a similar way as the vibration. The light intensity at its maximum level was 36 cd/m^2. Finally, the sound was a repeated sequence of two notes: a La-small (frequency 220 Hz) was played for 250 milliseconds followed by a Sol-small (frequency 196 Hz) for 250 milliseconds. The sequence was repeated every 2 seconds. A more melodic output would also have rendered the stimuli more complex, and potentially evoke reactions linked to cultural or memory preferences (e.g. appreciating certain melodic phrases); thus the sound behaviour would have been a significantly more complex stimulus than those generated by the other behaviours. In addition, the buzzer was small enough to fit in our Small objects that were under 8cm.

A rechargeable battery pack completed the core of electronics. The board, the battery and the sensors were encased in a clear plastic box fitted within the objects (Fig. 1, front bottom right, size 63x35mm). Padding was used to keep the electronics core in place and to prevent it from rattling when the objects were moved. The LED, the sound buzzer and the motor vibration were located close to the outside of the objects to assure that the behaviour was clearly perceivable by the participants. The spheres were bought ready-made, while we laser-cut the plastic cubes and hand-sewed the canvas objects. The weight of the objects of the same size was almost the same across behaviours (a few grams difference). A small wooden block was embedded in the quiescent objects to give it a weight comparable to the others.

FIGURE 1 HERE

It should to be underlined that the aim of this study was to measure participants' reaction to real IOs in multi-sensorial stimulation. To achieve this aim, real 3D objects needed to be created. This method has some limitations that impede some variables to be controlled with the same level of detail that it can be done with virtual objects simulated on a computer monitor. In particular, materials do not only vary in terms of texture quality but also in terms of colour and regularity. In addition, given the physical constraints of dimensions of the Arduinos, IOs size was constraint and objects could not be smaller than 8 centimetres.

2.2 Procedure

To investigate a participant's initial reaction, all objects were covered by a box; participants were requested to open the box; pick up the object (thus triggering its behaviour); hold it and explore it as much as they liked; put the object down and cover it before moving on to the next concealed object (Figure 2). A pilot with all 32 objects highlighted the fact that the full task was too long. Therefore, to prevent experimental fatigue, the IOs were split in two sets with respect to their size. The 175 participants were randomly assigned to one of two rooms that contained IOs all of the same size (see Figure 2 for experimental setting in the room with large objects). Size was then a between factor and each participant was presented with 16 interactive objects only that were combining material, shape and behaviour. The two groups were almost equal in size with 88 and 87 participants each.

FIGURE 2 HERE

Participants interacted with each object presented in a random order by revealing it and picking it up; when all 16 had been visited, participants were requested by a research assistant to select the IO they liked the most and the one they liked the least and to say why. Participants were required to write their preferences on a proforma and their responses were then transcribed for analysis.

2.3 Results

The responses the participants used to describe the objects they liked or disliked were analysed thematically (Braun & Clarke, 2006). More specifically, adjectives were extracted from the narratives collected: terms were thematically analysed to determine the most common dimensions. For example, the narrative ‘The plastic cube. It is hard and boring’ gave the adjectives ‘hard’ and ‘boring’, while ‘The texture of the material, comfort. The mobile vibration, curiosity, playful’ offered as explanation of why the large vibrating cube in fabric was liked, and gave ‘comfortable’, ‘curious’, ‘playfulness’ as qualities. Synonyms and antonyms were then paired to define dimensions of qualities across those two extremes. For example, ‘smooth’ / ‘soft’ and ‘comfortable’ / ‘uncomfortable’ are all adjectives used to define the quality ‘comfort’.

The seven dimensions that resulted from the thematic analysis were: 1) Interesting, 2) Comfortable, 3) Playful, 4) Surprising, 5) Pleasant, 6) Special and 7) Relaxing. In defining the dimensions, an effort was made to use terms that could be applied to both form factors and behavioural IOs features, as the aim was to capture the effect of the combination of the two. In fact, most narratives mentioned both structural and behavioural features as motivations for liking or disliking an object, for example ‘the smooth surface of the cube and the light made me smile’ and ‘too solid, did not like the beeping’ for the large plastic cube with sound. This seems to indicate that the structural and behavioural properties of an interactive object are equally important for the participants and both influenced their judgements.

An analysis of the narratives collected over the full study shows that over a third were abstract judgements, for example ‘cool’ or ‘simple’, used to describe their like and dislike respectively. A sign-test analysis showed that most of the narratives referred to both form and behaviour at the same time, rather than to a single characteristic ($p < 0.01$). When only one feature was used the reference to the IO's behaviour was slightly prevalent (55%). It can be concluded that when participants are requested to describe an IO, both form and behaviour contribute to their descriptions. Moreover the terms extracted as dimensions were used interchangeably for describing form or behaviour, as in the example of ‘comfortable’ in the narratives ‘I like the vibration – felt comfortable’, ‘dim lighting makes me comfortable’ and ‘it’s soft, round, comfortable’, that capture the reaction to both behaviour and form.

Most objects provoked polarised preferences; they were coherently liked or disliked. For example, the rounded-rough-vibrating objects were mostly liked and described, for example, as "soft and made me chuckle" or "this surprised me and it is playful"). Angular-smooth-quiescent objects were mostly disliked and described, for example, as "hard, angular, no interesting features" or "didn't find the purpose".

However, few objects were almost equally liked or disliked. For example, angular-rough-lighting objects were liked by some and described, for example, as "because I like the shape and with the light" or "it let me feel most relaxing"; and disliked by others and described as "it was square and plain, it did not interest me" or "rigid, nothing special".

3. STUDY 2: MEASURING THE AESTHETICS OF INTERACTIVE OBJECTS

In the first study, seven main dimensions were identified along which participants expressed their reasons for preferring particular object-behaviour combinations. This was an exploratory qualitative study designed to elicit these dimensions from participants.

The purpose of this second study was to systematically measure responses of participants to each of the objects they interacted with along all seven of these dimensions and then to examine how object properties and combinations of properties influenced ratings on the dimensions. Specifically, the second study aimed to measure the influence of different structural and behaviour features of IOs on aesthetics.

3.1 Method

3.1.1 Participants

486 volunteers took part in the second study. 267 males and 219 females, aged between 18 and 69 (mean of 26.89). For 266 participants English was their first language. None of the participants that took part in the first study took part in this second one. Fifty of these participants omitted ratings on one or more of the dimensions and thus were not included in the analyses. Thus, 436 participants provided ratings and were included in the analysis. These participants had a mean age of 26.85 (ranging between 18 and 69); 243 had a first language of English. 222 participants were allocated to the small object room and 214 allocated to the large object room. An a priori power analysis with GPower for the between-participants and within-participants interaction suggested that 314 participants would be required (suggested power of 0.8, α=0.05 and a medium effect size). A post hoc power analysis using GPower suggests that the current study has a power of 0.93.

The experiment was carried out according to our institution guidelines for ethical issues and in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained from participants.

3.1.2 Apparatus and Stimuli

The experimental setting and the objects were the same as were used for the first study. There were two separate rooms, one containing large objects only and the other small objects only. Each participant interacted with objects in one room only; that is, they interacted with either large or small objects, not both. In this study the following object variables were controlled: IOs' size (small vs. large - between subjects); IOs' contour (rounded vs. angular); IOs' surface texture (rough vs. smooth); and IOs' behaviour (light, sound, vibrate, and quiescent); and for the following "participant" variables: age, gender and first language

To minimise participants' fatigue, the variable IOs size was manipulated between-subjects. In doing this, however, the relevance of size was not directly compared with the other variables. This problem was solved by running a control experiment which is described below.

3.2 Procedure

Participants had to open one box at a time, presented in random order, interact with the object within, and then rate it on each of the 7 dimensions identified in study 1. That is, participants had to indicate how Interesting, Comfortable, Playful, Surprising, Pleasant, Special and Relaxing each object was on a scale of 1 to 7 where in each case a rating of '7' indicated the positive end of the dimension being examined (e.g. a rating of 7 would indicate that an object was extremely interesting). The dimensions were also presented in a random order. At the debriefing participants provided personal information, namely age, gender and first language.

3.3 Results

3.3.1 ANOVAs

The data from each of the seven dimensions were analysed separately using four-way mixed ANOVAs with IOs' Contour (rounded vs. angular), IOs' surface texture (rough vs. smooth) and IOs' Behaviour (vibration/light/sound/quiescent) as within-participant variables and IOs' size (small vs. large) as the between-participants variable. The dependent variables were each of the seven rated dimensions (Interesting, Comfortable, Playful, Surprising, Pleasant, Special and Relaxing).

All four-way interactions in these ANOVAs were non-significant at an α level of 0.01 (all Fs <= 3.18; ps >= 0.023). There were few significant interactions involving IO's size, the first of these was the playful dimension were the IO's size x IO's behaviour interaction was significant ($F(2.80, 1238.88) = 5.01$, $p = 0.002$, $\eta_p^2 = 0.011$). This interaction suggested that big IOs rated higher for all behaviours except vibration where small IOs were rated higher. There was also a behaviour by surface texture by size interaction for playful and relaxing (Fs > 3.90, ps < 0.01, η_p^2 => 0.009 for both dimensions). This showed that for smooth textures large IOs were rated higher for all behaviours except vibration where the small IO was rated higher. For rough textures, big IOs were rated more playful for all behaviours except vibration where they were rated as equally playful. There were no other significant effects involving IO's size (all Fs < =3.80, all ps >= 0.014).

For all dimensions except surprising, the within-participants main effects were significant (all Fs >= 7.09; ps <= 0.008, η_p^2 => 0.016). For surprising the main effect of contour was not significant ($F(1,444) = 4.31$, $p = 0.038$, $\eta_p^2 = 0.010$). Of the main effects, the effect of IO's behaviour tended to have the largest effect size and thus seems most influential for accounting for the variation in ratings. For all dimensions, except comfortable and relaxing, IO's behaviour showed the largest η_p^2. The η_p^2s for IO's behaviour were (0.11, 0.41, 0.31, 0.23, 0.17, 0.34 & 0.44 respectively, for comfortable, interesting, playful, pleasant, relaxing, special & surprising), the equivalent η_p^2s for IO's surface texture were (0.35, 0.05, 0.18, 0.16, 0.23, 0.07 and 0.10) and for IO's contour were (0.33, 0.02, 0.26, 0.14, 0.21, 0.05 & 0.01).

There were also a large number of significant two-way interactions involving the within-participant IVs. However, these were all subsumed within significant three-way interactions involving IO's behaviour, IO's surface texture and IO's contour for comfortable, interesting, special and surprising (all $Fs > 4.75$, $ps < .004$, $\eta_p^2 = 0.012$, 0.014, 0.011 and 0.022, respectively). For playful, pleasant and relaxing there were significant behaviour by surface texture (all $Fs = 4.93$, all $ps <= .002$, all $\eta_p^2 >= 0.011$) and behaviour by contour (all $Fs = 6.74$, $p < 0.001$, all $\eta_p^2 >= 0.015$) interactions. Additionally for relaxing there was a significant surface texture by contour interaction ($F(1,440) = 12.43$, $p < 0.001$, $\eta_p^2 = 0.027$).

Decomposition of the two-way interactions showed that for playful for rough IOs vibration was rated significantly higher than all other behaviours and light and sound equally higher than quiescent (all significant $ps < 0.001$). For smooth IOs all pairwise comparisons were significant with vibration rated highest followed by light, then sound and finally quiescent (all $ps < 0.001$). For the behaviour by contour interaction for angular and rounded IOs all pairwise comparisons were significant (all $ps <= 0.001$). For both types of IO vibration was rated highest followed by light, sound and then quiescent. The interaction seems to stem from the fact that the difference in ratings between angular and rounded IOs seems to be considerably smaller for vibration than the other three behaviours.

For pleasantness ratings for both rough and smooth IOs, vibration and sound were rated equally and these were both significantly higher than sound and all were significantly higher than quiescent (all significant ps <= 0.002). When comparing across IOs for each behaviour, there was no significant difference between rough and smooth IOs for light as the behaviour whereas for the other behaviours rough IOs are always rated higher than smooth IOs (all ps < 0.001). For the behaviour by contour interactions, the ratings for both angular IOs vibration and light were rated equally and these were both significantly higher than sound and all were significantly higher than quiescent (all significant ps < 0.001). Whereas for rounded IOs vibration and light were rated equally as were sound and quiescence. Moreover, vibration and light were rated significantly higher than sound and quiescence (all significant ps < 0.001).

For relaxing ratings for rough IOs vibration and light were rated equally higher than both, sound and quiescence, the latter behaviours also being rated equally (all significant ps < 0.001). For the smooth IOs light was rated highest followed by vibration which was rated higher than both sound and quiescence, that latter behaviours being rated as equally relaxing (all significant ps < 0.001). For the behaviour by contour interaction for angular IOs light and vibration were rated equally highly and these rated higher than sound which was rated higher than quiescent (all significant ps <= 0.002). For the rounded IOs all pairwise comparisons were significant with light being rated highest, followed by vibration then quiescent and finally sound (all ps <= 0.005). For the surface texture by contour interaction, all pairwise comparisons were significant (all ps < 0.001). The interaction appears to be accounted for by the difference between angular and rounded IOs is larger for rough surfaces than it is for smooth surfaces, with rounded IOs preferred for both surface textures.

The significant three-way interactions for comfortable, interesting, special and surprising were initially followed up by examining the two-way interactions between behaviour and surface texture separately for angular and rounded IOs. All of these two-way interactions were significant (all Fs >= 4.02, all ps <= .008, all η_p^2 >= 0.009) except for the rounded IOs for the comfortable ratings ($F(2.93, 1308.78) = 3.22$, $p = 0.023$, $\eta_p^2 = 0.007$).

To examine the significant two-way behaviour by surface texture interactions the main effect of behaviour was examined for each surface texture separately. All these main effects were significant (all Fs >= 24.81, all ps < 0.001, all η_p^2 => 0.12). For each of these main effects of behaviour Bonferroni adjusted post hoc pairwise comparisons were conducted and thus all differences where $p < 0.05$ are reported as significant. For the comfortable rating these showed that rough angular quiescent IOs were significantly lower than all other behaviours, and light was significantly higher than sound. For smooth angular IOs vibration and light rated equally significantly higher than sound and quiescent and sound rated higher than quiescent (all significant ps <= 0.005). For interesting ratings for rough angular IOs vibration, light and sound were equally significantly higher than quiescent (all significant ps < 0.001). For rough rounded IOs, vibration was rated higher than all other behaviours, light was rated equal to sound, which were both rated higher than quiescent IOs (all significant ps < 0.001). For smooth angular and rounded IOs all pairwise comparisons were significant with vibration rated highest followed by light, then sound then quiescent (all ps <= 0.009). For special ratings for rough angular IOs all pairwise comparisons were significant with vibration highest followed by light, sound and finally quiescent. For rough rounded IOs vibration higher than all other IOs, light and sound equal but significantly higher than quiescent (all significant ps <= 0.001). For smooth angular and rounded IOs all pairwise comparisons significant (all ps < 0.001) with vibration rated highest followed by light, then sound and finally quiescent. For surprising ratings for rough angular and rounded IOs vibration significantly higher than all other, light and sound equally significantly higher than quiescent (all significant ps < 0.001). For smooth angular and rounded IOs all pairwise comparisons significant with vibration rated highest followed by light, then sound and finally quiescent (all ps < 0.001). Figure 3 shows the ratings for each IOs grouped according to their level of the IOs' contour and IOs' surface texture variables (as IOs' size had no significant effect on any of the dimensions these data have been collapsed).

FIGURE 3 HERE

Figure 4 shows the same ratings as figure 3 but separately for each dimension.

FIGURE 4 HERE

As can be seen from figures 3 and 4, overall the quiescent objects consistently received lower scores for all the dimensions showing that the interactive objects with behaviours were preferred to quiescent objects, regardless of the added behaviour. Furthermore, the vibrating objects were generally preferred over those emitting light, and light was preferred over sound. The fact that the sound was the least preferred behaviour should be taken with caution: as discussed before, instead of a modulated sound, for a number of reasons, we chose to use a buzzer. Therefore, this may have led many participants to finding the sounding objects less appealing. It is worth noting that consistent with study 2, many of the participants in study 1 rated them as the least liked objects.

3.3.2. Underlying dimension analysis

To explore the structure of the seven dimensions being used by the participants, ratings of all dimensions were factor analysed. To do this we converted the 486 participant x 112 ratings matrix into a ‘long thin’ matrix with 7 columns, each corresponding to one dimension (e.g. interesting, playful, etc.) and 7776 rows (486 x 16). Principal components analysis showed just one component with eigenvalue greater than 1 and the scree plot also supported that one component summarises the results appropriately. This single component can be named "Aesthetics of IOs" and appears to represents how much each object was valued overall. At this point, factor scores for each IOs were obtained and used as a condensed dependent variable in a four-way mixed ANOVA, which employed the same independent variables - IOs' Contour, IOs' surface texture and IOs' Behaviour as within-participant variables and IOs' size -as the between-participants variable - used in previous analysis.

The main effects confirmed that IO's behaviour has the largest effect size ($F(3, 1254) = 232.4$, $p < 0.01$; $\eta_p^2s = 0.36$), followed by the main effects of IO's Surface Texture ($F(1, 418) = 146.8$, $p < 0.01$; $\eta_p^2s = 0.26$) and IO's Contour ($F(1, 418) = 102.22$, $p < 0.01$; $\eta_p^2s = 0.2$). The main effect of IO's size was not significant ($F(1,418) = 1.59$, $p = 0.21$).

The three way interaction among the three within subjects variables was non-significant ($F(3,1254) = 0.74$, $p = 0.53$) as were the two-ways interactions between the between subjects variable IO's size and the within subjects variables ($p=> 0.3$).

The two ways interactions among each pair of the three within subjects' variables were non-significant ($p=>0.2$) with the exception of the interaction between IOs' Contour and IOs Behaviour which showed a small effect size ($F(3,1254)=6.07$, $p < 0.01$; $\eta_p^2s = 0.014$). Pairwise comparisons were significant for all IO's Contour x IO's Behaviour ($p < 0.001$) - indicating that for all behaviours rounded objects were favoured over angular objects - with the exception of sounding IOs. Therefore, this interaction seems to indicate that whilst sounding IOs were rated less favourable than lightning and vibrating IOs in both levels of IOs' Contour, this difference was slightly smaller for angular IOs than rounded IOs. Figure 5 shows the factor scores of this Aesthetics of IOs variable for each of the IOs. This shows clearly that quiescent objects had lower scores than those objects with behaviours.

FIGURE 5 HERE

3.3.3. Q-Mode analysis

Considering the high number of participants in this study, it is interesting to measure individual differences in aesthetic judgments. We analysed the structure of the differences using a Q-mode factor analysis (as was carried out by McManus, 1980; and McManus, Cook & Hunt, 2010). As a difference from conventional factor analysis, Q-mode analysis transposes the data matrix so that the correlations analysed are not between the objects but instead are between the participants. Specifically, the ratings data matrix was transposed such that the variables (IOs ratings) became cases and the participants became the variables. This new data matrix with 112 cases and 421[2] variables was then subjected to a principal components analysis with varimax rotation. This analyses suggested that there were two components which best represented the data. The scree plot suggested more than two components (the first ten eigenvalues were: 90.44, 27.27, 19.03, 14.81, 13.71, 12.35, 12.11, 11.05, 10.70 & 10.32) but examination of the components beyond the second one suggested no meaningful pattern of component scores for any of these components. The two main components accounted for 28% of the total variance which is large considering the number of variables included in the analysis (421). Component scores for the two meaningful components were calculated and then plotted against IO characteristics in order to provide an interpretation of these. The scores were initially plotted against each type of IOs (e.g.

[2] There were 421 variables rather than 490 as all participants who had missing data were removed from the analyses to ensure that all ratings of the IOs were included in the analyses.

lighting-rough-angular) for both components but no obvious pattern emerged. The first component was then plotted against IOs' behaviour and this suggested that this component best represented a dislike of IOs, with the quiescent IOs having the higher scores and vibrating IOs having the lowest scores. Given the positive ratings observed for the vibrating IOs in the main analyses and the negative component scores for these IOs presented in Figure 6a this suggests that the component represents a dislike rather than a preference for IOs. These findings confirm that IOs' behaviour represents the fundamental dimension upon which IOs are primarily judged by participants. Plotting the components scores for the second component suggested that this was related to a dislike of a combination of IOs' texture and contours (i.e. IO's form characteristic) such that it represents a dislike of rough angular IOs (Figure 6b). Again, this being represented a dislike rather than a preference concurs with the findings from the main analyses which suggested a preference for rounded IOs but that difference between angular and rounded IOs was larger for those with rough rather than smooth surface textures.

FIGURE 6 HERE

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4. STUDY 3: CONTROLLING SIZE

To minimise experimental fatigue in the previous studies the IOs were split into two sets with respect to their size. The variable IOs size was selected as between subjects. In doing this, the relevance of this variable was not directly compared with the other variables. For this reason, a control experiment was designed to test the effect of size within participants. To minimise experimental fatigue, in this third experiment the variable IOs' surface texture was not manipulated and only smooth objects were used.

4.1 Method

4.1.1 Participants

Thirty-two new volunteers took part in the third study. 8 males and 24 females, aged between 18 and 49 (mean of 25.68). An a priori power analysis with GPower for the within-participants interaction suggested that 30 participants would be required (suggested power of 0.8, α=0.05 and a medium effect size). A post hoc power analysis using GPower suggests that the current study has a power 0.97.

The same guidelines as for previous studies were followed for ethical issues and informed consent was obtained from participants.

4.1.2 Apparatus and Stimuli

The experimental setting and the objects were the same as for the previous studies but only one room was used. The following within-subjects variables were controlled: IOs' size (small vs. large); IOs' contour (rounded vs. angular); and IOs' behaviour (light, sound, vibrate, and quiescent). Since in previous studies no "participant" variable was found to influence any of the considered aesthetic dimensions, participant variables were not controlled in this experiment.

4.2 Procedure

The procedure was the same as in study 2.

4.3 Results

The seven dimensions were analysed separately using seven three-way repeated measures ANOVAs with IOs' size (small vs. large), IOs' Contour (rounded vs. angular) and IOs' Behaviour (vibration/light/sound/quiescent) as within-participant variables. The dependent variables of each of the seven ANOVAs were: Interesting, Comfortable, Playful, Surprising, Pleasant, Special and Relaxing.

As expected, the main effect of IO's size was not significant in any of the dimensions considered ($F(30,1) <= 3.75$, $p => 0.06$).

The other main effects were in line with those which emerged in study 2, with IO's behaviour showing the largest effect size (η_p^2s => 0.38); this confirms that the most influential factor for accounting for the variation in ratings is IO's behaviour. The η_p^2s for this variable were (0.52, 0.87**,** 0.38**,** 0.74**,** 0.85, 0.69 & 0.71**,** respectively, for comfortable, interesting, playful, pleasant, relaxing, special & surprising), the equivalent η_p^2s for IO's contour were (0.22, 0.16, 0.20, 0.22, 0.23, 0.01 & 0.06).

The three way interactions among the three variables were all non-significant ($F(28,3)<= 0.3$, $p = 0.8$).The two-ways interactions between IO's size and either IO's contour or IO's behaviour were all non-significant ($F(30,1) <= 2.11$, $p=> 0.16$ and $F(28,3) <= 2.13$, $p=> 0.12$, respectively). The only exception was the two-way interaction between size and contour in the Interesting dimension ($F(30,1) =7.9$, p. = 0.008). A post-doc analysis showed that small cubes were significantly less interesting than large ones ($p=0.004$).

Figure 7 shows the ratings for each of the IOs grouped according to their level of the IOs' contour and IOs' size variables.

FIGURE 7 HERE

Figure 8 shows the same ratings as figure 7 but separately for each dimension.

FIGURE 8 HERE

As can be seen in figures 7 and 8, the results of study three are in line with the results of study two: behaving IOs were preferred to quiescent ones and vibrating objects were generally preferred over those emitting light, and light was preferred over sound. Rounded objects were preferred over angular IOs. The key finding though for the purpose of this study was the lack of an overall effect of size on ratings.

4. DISCUSSION

We have argued how, thus far, the aesthetic preference for perceptual characteristics of stimuli has been mainly studied for each sense in isolation. The smooth curvature effect (Hogarth, 1753; Bar & Neta, 2006; 2007; Varatanian et al. 2013; Bertamini et al. 2016; Paulumbo, Ruta & Bertamini, 2015) or the size effect (Silvera et al. 2002) have been mainly studied in vision. Conversely, the effect of surface texture (Ekman, Hosman & Lindstrom, 1965; Rowell & Ungar, 2003; and Jehoel et al. 2005) has been tested on haptic perception only. It should be considered that aesthetic preferences are likely to derive from a combination of factors and be related to the full hedonic experience. To this end, we measured the aesthetic response to interactive objects (IOs), which are three-dimensional physical artefacts that exhibit autonomous behaviour when handled.

Prior to the experimental investigations, a qualitative study was conducted aimed at individuating the dimensions along which people rate aesthetic preference. A thematic analysis of participants' responses to handling the IOs revealed the following seven dimensions: interesting, comfortable, playful, surprising, pleasant, special, and relaxing.

Most participants' descriptions refer to more than one IOs' dimension at the same time. It seems therefore that aesthetic perception in complex interactions is better captured by a combination of dimensions; the like/dislike dimension, usually used to study aesthetic stimuli in simplified conditions, might not be sufficient to capture the complexity of the aesthetic experience. Four of the aesthetic dimensions that emerged in this study (interesting, comfortable, relaxing & pleasant) map onto those tested by Biaggio & Supplee (1983) although we contribute with the following further dimensions that may be more specifically related to the behavioural features of IOs: playful, special and surprising.

It is interesting to compare these dimensions with the study conducted by Augustin, Wageman & Carbon (2012) in relation to the terminology that people use to describe aesthetic impressions. These authors measured the frequency of words that people used to describe their aesthetic impression when presented with the following object classes: visual art, landscapes, faces, geometrical shapes, cars, clothing, interior design, and buildings. They found that besides the term "beautiful" people use very different terms to describe their aesthetic experience in reference to the different object classes. The IOs used in our study do not precisely match with any of the classes used by Augustin et al. Nevertheless, it is interesting to notice that results of their study showed that for visual art people include several terms that refer to the idea of being special, such as special and interesting. This corroborates our results; it may be speculated that our participants considered IOs, in some ways, as a form of art.

The seven dimensions from the first study were then considered in the second study to establish how different structural and behavioural features of IOs affect the aesthetics experience. Although differences were found for each dimension (i.e. a specific object scored high on one dimension but low in another one), some very interesting patterns of findings emerged.

Curvature

The existing literature shows that objects with curved contours tend to be preferred over objects with an angular shape - the "smooth curvature effect" (Bertamini et al. 2015). While previous studies used 2D pictorial representations of objects and focused on the visual sense only, our study shows this effect occurs with 3D objects that were both looked at (sight) and manipulated (touch). It seems therefore that the preference for curved objects is not limited to pictorial representations and to visual processing, but it is a general feature that extends to 3D objects and influences experience in more perceptual domains, i.e. sight and touch.

The limitations of the current study have however to be outlined. Due to the practical limitations of 3D objects made of different materials, our stimuli were not perfectly smooth and angular. Furthermore, we tested only two levels of curvature and both objects types were regular geometric solids. Further testing is needed to generalise the effects of curvature in 3D objects. Of particular interest would be to measure the aesthetic responses in relation to complex irregular tetragons with sharp and soft contours.

Surface texture

As mentioned in the introduction, the effects on aesthetic preference for the smoothness of surfaces are controversial. On one side Ekman, Hosman & Lindstrom (1965) found that finer-grained paper was preferred to the touch over coarse sandpaper, whilst, on the other hand, Jehoel et al. (2005) found opposite results by testing different materials (such as different types of plastic, paper, PVC and aluminium). In our study, we compared smooth plastic against rough fabric and found that the rougher textured fabric was preferred over the smoother plastic, supporting Jehoel et al.'s findings. As a difference from Jehoel et al's study, however, the effect emerged in a complex stimulation where, beyond touch, the visual and aural senses were also engaged in judging the objects. It seems therefore that in compound stimulation rough texture is preferred over smoothness. Further investigation is needed to better understand if rough texture can be considered as an aesthetic primitive, as our stimuli differ also for other factors, i.e. hardness, temperature, and naturalness (natural material over a clearly synthetic one).

Size

This study found no difference between the two objects sizes considered, with the exception for the playfulness dimension in study 2 where small objects were rated more playful than large objects. To control for this effect (or lack of effect) a control experiment, study 3, was conducted which confirmed that size does not affect the aesthetics of IOs. Hence, our study does not confirm the large size effect suggested by Silvera. Josephs & Giesler (2002). There are of course differences in the methodologies of the studies, the main one being that Silvera. Josephs & Giesler . presented their stimuli pictorially rather than using physical objects. It might be that the presentation modality is a discriminatory and determining factor. In any case, the large size effect does not seem to be an effect that applies to physical objects but that may be perceptual modality and/or presentation modality dependent. It has also to be noted that our conclusion derives from the study of two sizes only and that IOs smaller than 7.5 cm could not be used as there would be no room to fit the electronics.

Behaviour

Interactive objects were rated aesthetically more pleasant than quiescent objects. Vibration was more positively rated than any other behaviour in most of the dimensions. Light and sound were rated more positively than no behaviour (quiescent objects). However, subtleties arise in the comparisons with sound and light. Sometimes light and sound are rated equally (as for the Special dimension for rough textured objects), and sometimes vibration is rated close to light (as for the Pleasant dimension for spheres). In addition, sometimes there appear to be differences in the magnitude of the main differences between factors. For example, the difference between 'relaxing' ratings for rough textured versus smooth spheres is not as large as that for cubes. This could be explained by considering the combined effect of the IOs' texture and shape: a cube made of relatively soft material (fabric) is less sharp to handle than the same shape made of a rigid material (plastic). It is worth noting here that the effect sizes for the main effect of behaviour were generally much larger than those for the other main effects and also the interactions. This suggests that, for the aesthetic dimensions considered in this study, behaviour accounted for more variation in participants' ratings than any of factor or combination of factors.

The most prominent outcome of the analysis regarding the behaviour of IOs is that IOs with an embedded behaviour are judged more aesthetically pleasing than quiescent IOs, possibly, because an object that looks as any other suddenly displaying an autonomous behaviour is still unusual in our daily experience, thus generating arousal or surprise. In other words, "novelty" might have played a role in this preference. In particular, Humphrey (1972) showed that the "interesting" dimension is mainly being driven by novelty. It could be therefore that novelty made the objects more interesting and, in general, more pleasing overall in comparison with quiescent objects. It should be noted, however, that besides measuring the dimension of "interesting-ness" or "surprising-ness " participants were explicitly requested to rate the objects in terms of "relaxing-ness" and "comfortable-ness". An explanation based purely on arousal or novelty would predict the effect of the former but not of the latter dimensions. Indeed, the ratings for the relaxing and comfortable dimensions did decrease compared to the others dimensions, but the effect of any-behaviour preferred over quiescence did not completely disappear (with few exceptions of quiescent objects preferred over sounding objects).

Although an explanation of the "behaviour effect" based on arousal or novelty cannot be ruled out, it seems that these aspects by themselves are not sufficient to explain the role of behaviour in aesthetics. As the effect of behaviour was so robust and consistent, and as it occurs (even if reduced) for dimensions that are not directly related to arousal, it can be suggested that "behaviour" may be an aesthetic primitive in Latto (1995)'s terms.

It is known that moving stimuli attract attention and arousal more than static stimuli (Franconeri & Simons, 2003) and aesthetics positively correlate with arousal (Marković, 2012). IOs' reaction to the user can be intended, in some way, as moving stimuli. It can therefore be hypothesised that IOs enhance arousal and this improves the aesthetic experience.

Another possible interpretation of the effect of behaviour in aesthetics is the fact that the objects produced behaviour *in response to* the action of the participants. They activated when picked up and stopped when put down. It could be argued that objects have actively "interacted" with the participants, "acknowledging" that they have been touched by them. In other words, the feedback provided by the behavioural objects to the participants' action of picking them up might work as a reward that is positively evaluated.

To better understand the role of behaviour as aesthetic primitive, further experiments are needed to measure the relative contribution of novelty, arousal, and feedback. Furthermore, now that we know that behaviour is an aesthetic feature by itself, it will be interesting to establish which the preferred parameters of each behaviour are (e.g. which is the preferred level of vibration, or preferred light intensity or chromaticity, etc.).

The discovery of the aesthetic preference for objects displaying behaviours might also contribute to the debate on the smooth contour effect that has been studied mainly in vision. As mentioned in the introduction, the 'threat hypothesis' suggested by Bar & Neta (2006) advances that the smooth curvature effect is secondary to actually disliking angular shapes. It might be argued that according to this hypothesis the difference between the preferences for smooth contours against sharp contours should increase when the objects also display behaviour. Indeed, it is reasonable to believe that a threatening quiescent object would be even more threatening if the object displays behaviour when picked up. In other words, if an angularly shaped object exhibits behaviour, this should be considered more threatening than a similar object that is quiescent. However, this is not what we found. Results show that angular objects displaying behaviours are preferred over quiescent objects and that the difference between the preferences for smooth contours against sharp contours actually reduces when objects display behaviours. This result does not support the 'threat hypotheses'. On the contrary, it seems that the smooth curvature effect is a genuine preference for curvature, rather than an avoidance of angular objects, as suggested by Palumbo, Ruta & Bertamini (2015).

The analysis of the overall aesthetic experience evidenced another interesting phenomenon, which is the relative importance of haptic processing. The importance of haptic processing was illustrated in the findings: the most positive ratings from participants for behaviour was for vibration as an individual factor (behaviour only) as well as when combined with other factors (e.g. shape and behaviour). This preference seems to be related to the haptic processing system and suggests that this was the key system (as opposed to visual or aural system) in the current task for determining participant ratings. Therefore, although vision is the perceptual system that humans utilize the most to explore the environment, it seems that human aesthetic experience when actively interacting with the environment strongly relies on the haptic system. This supports the view of Carbon & Jakesch (2013) that haptic exploration overpowers the other senses in terms of influencing our aesthetic evaluation of objects.

5. CONCLUSIONS

By studying the aesthetics of perceptual object features in compound stimulation, i.e. using interactive objects that stimulate more than one sense at the time, this work shows that there is a strong effect of behaviour in aesthetics. People across different age groups, gender and cultural background tend to prefer objects displaying behaviours rather than quiescent objects. In particular, vibration seems to be an important object feature in aesthetics. Our study also shows that rough textured objects are generally preferred over smooth ones; although it is still unclear what perceptual feature underlies this aesthetic preference, and if it can be generalized. Finally, our study supports the preference for rounded compared to angular objects and suggests that this may be a genuine preference for curved contours rather than an aversion for sharp edges.

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Figure Captions

Figure 1: The interactive Objects with different structures and two electronics boxes used for the behaviour (top right).

Figure 2. The experimental set up for the Large IO: 16 interactive objects per room are placed on 3 rows of desks. A box covers each object: in the picture all the boxes are open.

Figure 3: Experiment 2. Average score for IOs grouped according to their level of the IOs' contour and IOs' surface texture variables (as IOs' size had no effect on any of the dimensions these data have been collapsed). Bars represent standard errors.

Figure 4: Experiment 2. Mean score *for each dimension* of the IOs grouped according to their level of the IOs' contour and IOs' surface texture variables (as IOs' size had no effect on any of the dimensions these data have been collapsed) - error bars are standard errors.

Figure 5: Experiment 2. Factor scores of the *Aesthetics of IOs factor* for each IOs.

Figure 6: Experiment 2. Q-mode analysis. Summary of the dislike functions for (a) IOs' behaviour factor and (b) IOs's form factor.

Figure 7: Experiment 3. Average score for IOs grouped according to their level of the IOs' contour and IOs' size variables. Bars represent standard errors.

Figure 8: Experiment 3. Mean score *for each dimension* of the IOs grouped according to their level of the IOs' contour and IOs' size variables - error bars are standard errors.

Form			Behaviour
Contour	*Size*	*Surface texture*	
Round (sphere)	Small (7.5cm)	Smooth (plastic)	Emit a light
Angular (cube)	Large (15cm)	Rough (fabric)	Play a sound
			Vibrate
			Quiescent

Table 1

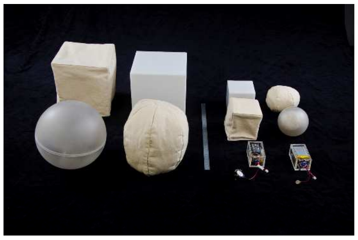


Figure 1: The interactive Objects with different structures and two electronics boxes used for the behaviour (top right).

1303x863mm (96 x 96 DPI)

Figure 2. The experimental set up for the Large IO: 16 interactive objects per room are placed on 3 rows of desks. A box covers each object: in the picture all the boxes are open.

111x69mm (96 x 96 DPI)

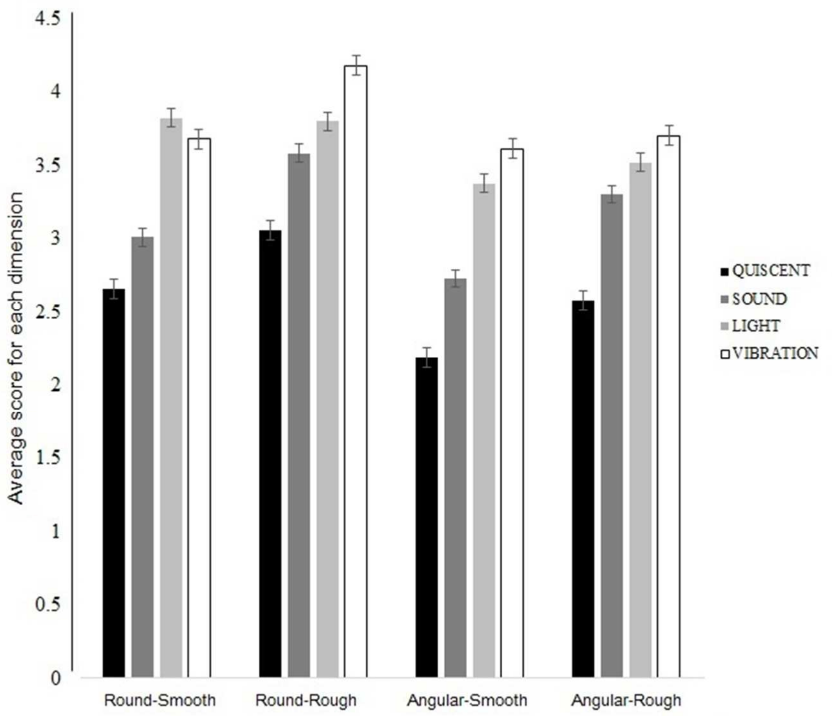


Figure 3: Experiment 2. Average score for IOs grouped according to their level of the IOs' contour and IOs' surface texture variables (as IOs' size had no effect on any of the dimensions these data have been collapsed). Bars represent standard errors.

203x147mm (96 x 96 DPI)

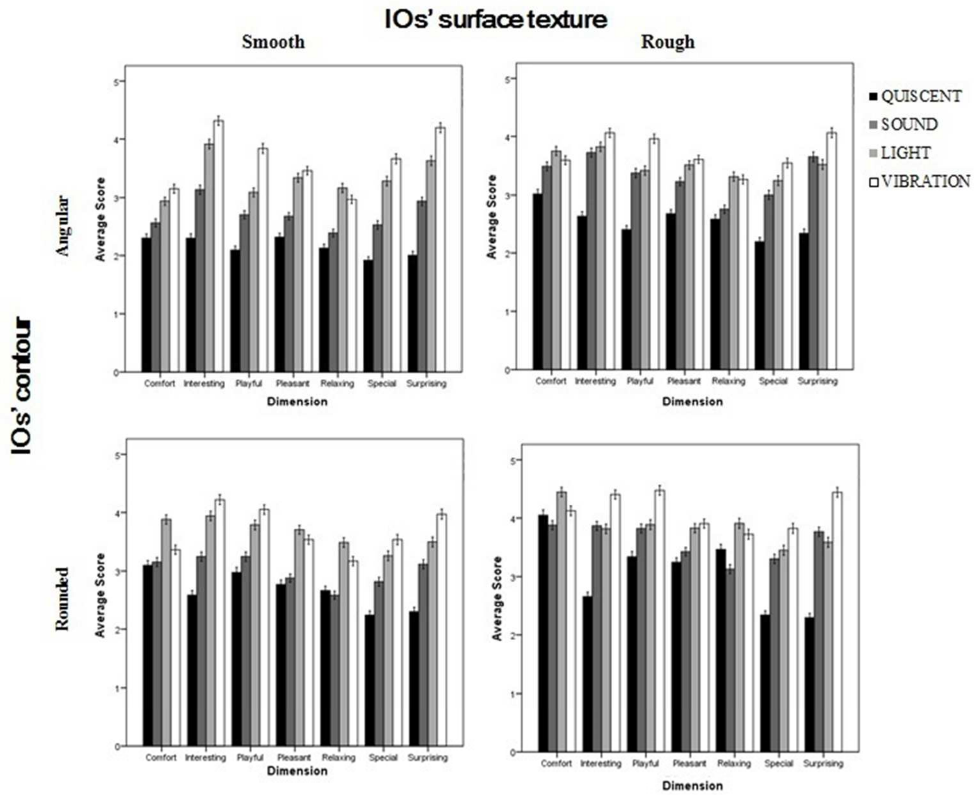


Figure 4: Experiment 2. Mean score for each dimension of the IOs grouped according to their level of the IOs' contour and IOs' surface texture variables (as IOs' size had no effect on any of the dimensions these data have been collapsed) - error bars are standard errors.

196x159mm (96 x 96 DPI)

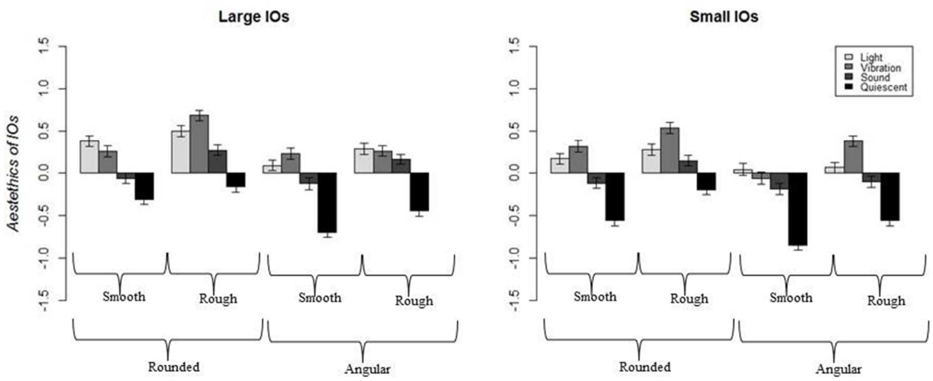


Figure 5: Experiment 2. Factor scores of the Aesthetics of IOs factor for each IOs.

254x190mm (96 x 96 DPI)

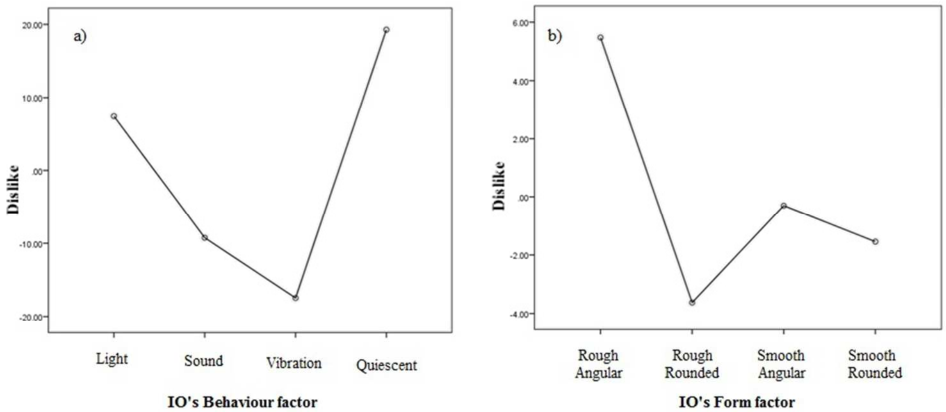


Figure 6: Experiment 2. Q-mode analysis. Summary of the dislike functions for (a) IOs' behaviour factor and (b) IOs's form factor.

243x104mm (96 x 96 DPI)

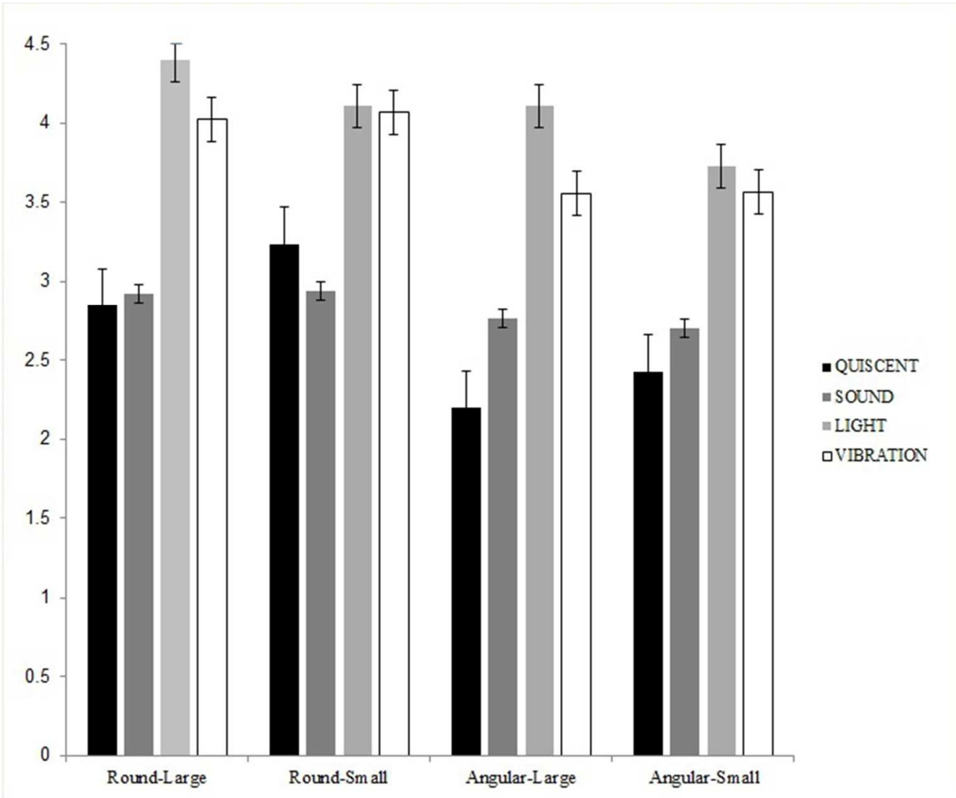


Figure 7: Experiment 3. Average score for IOs grouped according to their level of the IOs' contour and IOs' size variables. Bars represent standard errors.

189x152mm (96 x 96 DPI)

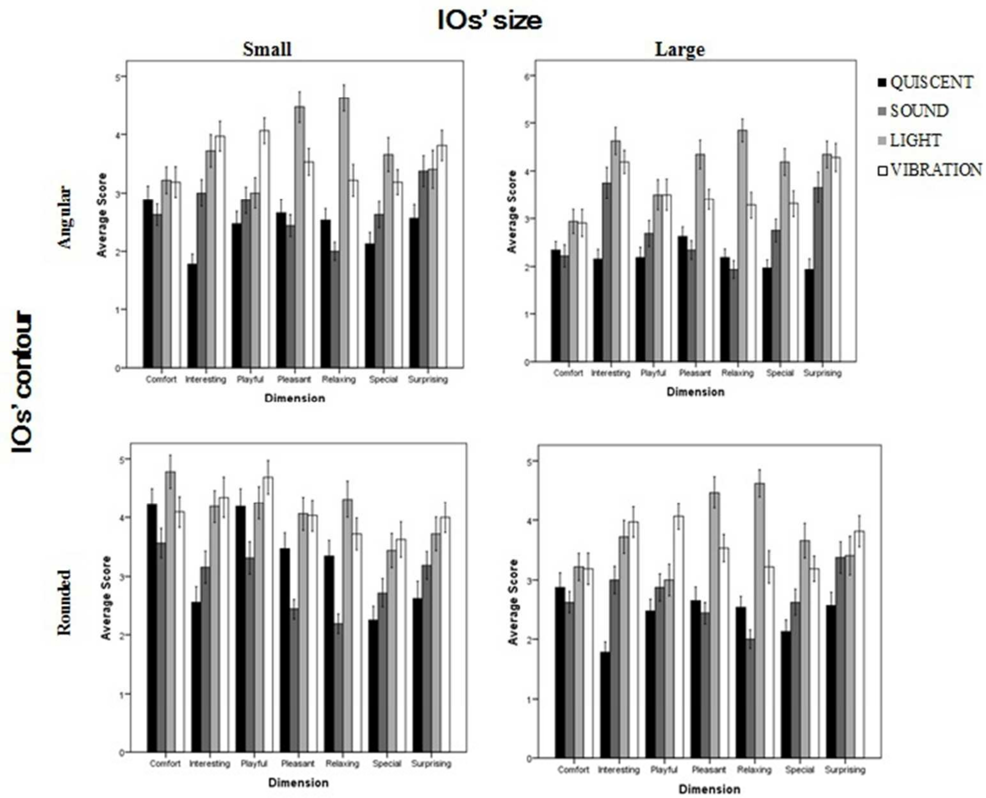
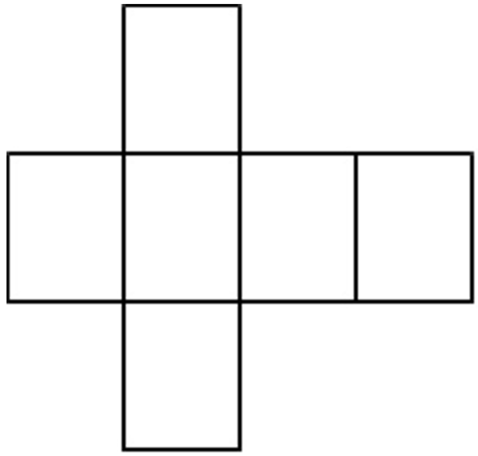


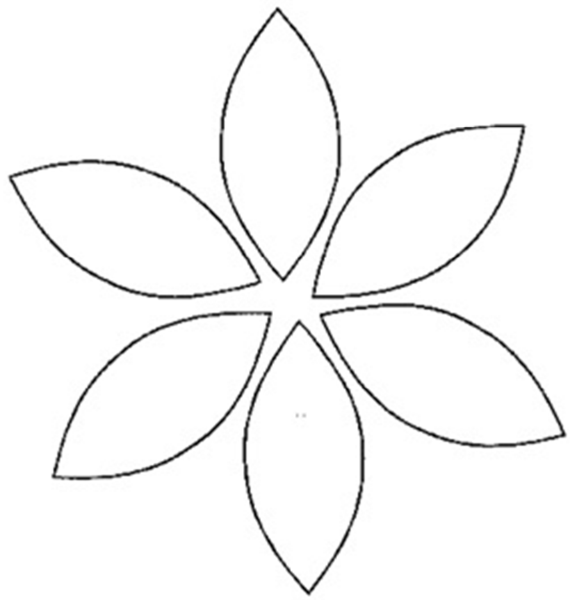
Figure 8: Experiment 3. Mean score for each dimension of the IOs grouped according to their level of the IOs' contour and IOs' size variables - error bars are standard errors.

189x153mm (96 x 96 DPI)



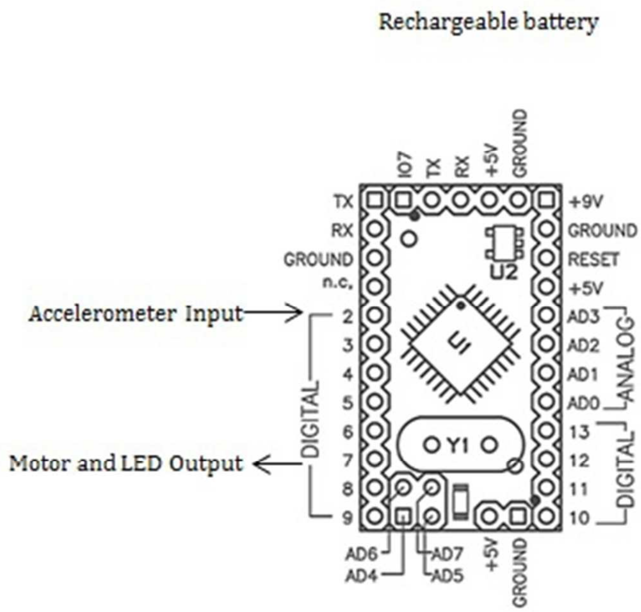
The pattern to make the fabric cubes.

74x68mm (96 x 96 DPI)



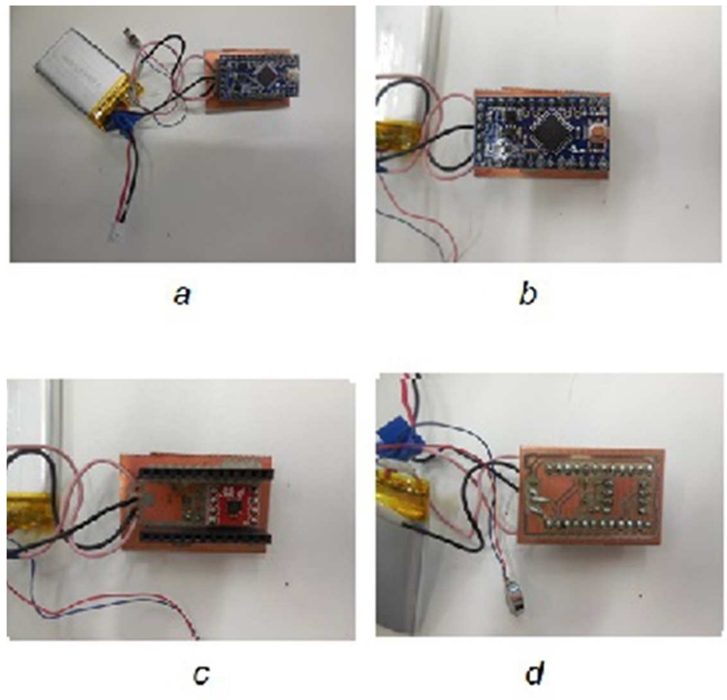
The pattern to make the fabric spheres

93x86mm (96 x 96 DPI)



The Arduino Mini board with input and output ports as used in the code

86x82mm (96 x 96 DPI)



The Arduino Mini board with input and output ports as used in the code.

96x95mm (96 x 96 DPI)