The Aesthetic Appeal of Prosthetic Limbs and the Uncanny Valley: *The Role of Personal Characteristics in Attraction*

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The aesthetics of prosthetic design is a field of study which until now has been subject to little investigation, and no research has been attempted before into the relationship of aesthetic attraction to devices and their human-likeness. The main aim of this paper is to explore this issue, testing the existence of a relationship between the Uncanny Valley (UV) (Mori, 1970) and prosthetic devices. The secondary aim is to explore whether or not attraction is related to the personal characteristics of the participants. We employed a cross-sectional questionnaire and involved 114 participants. The results did not demonstrate the existence of the UV for prostheses, as a high level of attraction to realistic devices was recorded; instead the data resulted in an "N-shaped" graph, showing only a small dip in attraction in relation to prostheses with human shape but with clear artificial patterns. Visual attraction to non-human-like devices was found, and the discriminating factors included gender and to a lesser extent nationality and the presence of amputation. This paper aims to set the basis for future investigations around the belief that prosthetic designs endorsing certain characteristics may be more suitable for some categories of prosthetic users in order to potentially achieve a greater satisfaction with their prostheses.

Keywords – Aesthetic Attraction, Amputees' Wellbeing, Prosthetic Devices, Uncanny Valley.

Relevance to Design Practice – This study proposes to be the first academic exploration of the "aesthetics of prostheses." The paper provides, as the main indicator, the factor of attraction of people to realistic devices, as well as a set of guidelines accounting for how people's personal characteristics may influence their aesthetic attraction towards the devices.

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Introduction

In addition to the physical change, the amputation of a limb can generate unpleasant psychological consequences (Horgan & MacLachlan, 2004; Price & Fisher, 2007; Shukla, Sahu, Tripathi, & Gupta, 1982; Whyte & Niven, 2001). Specifically, the literature shows that during the post-amputation phase, people can suffer symptoms such as stress and depression (Breakey, 1997; Cansever, Uzun, Yildiz, Ates, & Atesalp, 2003; Williamson, Schulz, Bridges, & Behan, 1994), and a general difficulty in accepting the new bodily condition (Sjödahl, Gard, & Jarnlo, 2004).

Interest in enhancing the self–body image and psychological wellbeing of amputees is an issue that has already been under consideration, and a functional prosthesis can undoubtedly be considered an important factor in this context. For instance, it has been stated that the use of a prosthesis helps the user to regain both mobility (Pohjolainen, Alaranta, & Kärkäinen, 1990) and the ability to return to performance of social activities (Murray, 2005).

Going beyond the functional role of the prosthesis, the literature shows how the aesthetic quality of the device influences the psychological concerns of amputees. Pillet and Didierjean-Pillet (2001) state: "No-one comes out unscathed by an amputation and a prosthesis may act as a security, a guarantee or a mechanism for requiring the integrity of one's physical appearance, which validates one's psychological integrity" (p. 528).

It has been stated that for prostheses to be accepted by users, they must be comfortable and functional, and must have a pleasant appearance (Millstein, Heger, & Hunter, 1986). Similarly, Bhuvaneswar, Epstein, and Stern (2007) report that "cosmetic appearance appears to play as great a role in psychological sequelae of amputation as does the return of physical function" (p. 306). Cairns, Murray, Corney, and McFadyen (2013) argue that the appearance of the prosthesis affects the acceptance of the device and, in the context of lower limb cosmetic devices, they state that improving the aesthetic quality of the prosthesis can consequently help to improve the self–body image and psychological wellbeing of the wearer.

Accordingly, it is our belief that the aesthetics of prosthetics can influence the psychological wellbeing of lower-limb amputees, and we believe that this principle should be accounted

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for in prosthetic design. Specifically, this paper investigates the role of the level of realism in prosthetics as a factor for generating attraction in amputees and non-amputees. Our belief is that there is no "standard beautiful design" for prostheses that fits the aesthetic needs of all users and observers, although a connection can be found with certain characteristics of prostheses which can meet the aesthetic requirements of specific groups (e.g., by gender or nationality).

Prosthetic Design

"Prosthetics" is a term that refers to devices designed to replace a missing part of the body. This definition applies to devices that replace a limb segment rather than externally applied devices which are referred to as "orthotics." For example, we can classify an artificial arm, leg, or finger as a "prosthesis," whereas external entities such as a dental brace, insoles, or a pair of glasses are "orthotics."

This study aims to explore the "aesthetics of prosthetic devices" by examining people's preferences for artificial limbs with either realistic or non-realistic appearances. The limited literature on the topic demonstrates that this field is still in its infancy. A review of current academic literature on prosthetic design shows that in contrast to the limited research around aesthetics, extended work to date has been largely focused on technical improvement of the devices (Cheetham, Suter, & Jäncke, 2011; Hahl, Taya, & Saito, 2000; Klute, Kallfelz, & Czerniecki, 2001; Mak, Zhang, & Boone, 2001). A recent popular example, showing the rapid technological improvement in prosthetic design, is offered by the design of a successfully functional prosthetic hand by the American citizen Paul McCarthy for his son Leon at the low cost of $10 (Reilly, 2013).

Stefania Sansoni is a PhD student in the Department of Design, Manufacture and Engineering Management at the University of Strathclyde investigating the aesthetics of prosthetic devices. She holds an MA from the University of Plymouth (UK) in Communication Design and was employed as graphic designer in industry for several years. Her research area is aesthetics of prosthetic devices, which aims to improve the emotional attachment of amputees to prosthetic devices and enhance their body vision. Her investigation employs a user-centered design approach, encompassing product design, psychology, emotional design and prosthetics.

Andrew Wodehouse is a design lecturer in the Department of Design, Manufacture and Engineering Management at the University of Strathclyde. He worked as a product design engineer for a number of design and technology consultancies before joining the University of Strathclyde, where he completed a PhD in interactive digital environments to support collaborative design. His current research areas include interaction design, product aesthetics and the drivers of innovation.

Angus McFadyen is now an independent statistical consultant, having spent over 30 years as a clinical statistician at a local university. He has published widely in areas including prosthetics and orthotics, physiotherapy, clinical rehabilitation, ophthalmology, occupational therapy, and veterinary science, and is an associate editor/statistical reviewer for several clinical journals. He also sits on both a local National Health Service and a UK ethics committee.

Arjan Buis has more than 29 years of experience in prosthetics, orthotics and biomechanical assessment. He has focused his research efforts on improving our understanding of the biomechanical mechanisms that contribute to the generation and control of load transfer forces, dealing with the subject of "where man meets machine" and especially the area of prosthetic socket fit. Beside his biomechanical interests he is also developing a portfolio in relation to component design related topics.

Few academic papers have been published on research into the aesthetics of prosthetic design. For example, Capestany and Esparza (2011) present a case study of an amputee who required a personalized design of prosthesis, based on the emotional need of the user: a golf prosthesis was made as this sport was an important activity in the user's social life. Plettenburg (2005) designed a prosthetic prehensor (of a design similar to a wrench) for children, using a combination of solid design and an appealing colorful style. This design was aimed at generating appreciation in users and their parents. Similarly, Hilhorst (2004) describes his design applied to prostheses for children, personalizing them for each person's "identity." While sharing the vision of the importance of the devices' appearance for users, the peculiarity of this paper is its focus on the level of realism in the devices as a major factor enhancing visual attraction. In order to investigate this issue, we included, as the main part of our investigation, the Japanese theory of the "Uncanny Valley," which we considered a suitable subject for our research.

The Uncanny Valley (UV) (Mori, 1970) is a theory that attempts to discover the level of familiarity and human-likeness of various entities through the level of acceptance that observers show towards them. After a selective literature search (performed in April 2014), we can state that little research exists around the topic "Uncanny Valley" related to "prosthetic devices." Beyond the presence of papers not directly relevant to the specific aim of this research (Bicchierini, Davalli, Sacchetti, & Paganelli, 2005; Vainshtein, 2012), the most relevant work to date is offered by Gee, Browne, and Kawamura (2005). This research offers a revised version of the UV and includes a small section discussing an experiment on prosthetic devices to "establish the effects of appearance where it is separated from motion and identify the preferred level of 'realness' which could be applied to external coverings for humanoid robots" (p. 156). The work of Gee et al. (2005) anticipates the aim of our paper and, despite its main focus on the UV for robotic devices rather than prosthetics, it is aligned with the goal of this research.

The major contribution of our work is to state whether the principle of the UV exists for prostheses and, specifically, which kinds of devices are aesthetically appreciated or disliked by certain categories of people. The exploration of this issue includes key questions such as:

- Do people prefer the appearance of a device similar to a real human limb with realistic details, or a device with a realistic shape but that is clearly artificial?
- What is the visual impact of robotic-looking devices that do not look like a real limb at all?

Specifically, the hypotheses of our investigation are: 1) According to the UV principle as applied to prosthetic devices, the level of human-likeness in prostheses produces an emotional response in observers (e.g., highly realistic prostheses generating repulsion or medium-realistic prostheses generating attraction). 2) The visual attraction to prostheses is connected to personal characteristics, such as gender (Salkind & Salkind, 1997), different cultural backgrounds (Miller, 1973) and presence of and length of time since amputation.

The Uncanny Valley

The Uncanny Valley (Mori, 1970) affirms that artificial entities trying to reproduce human features (e.g. robots, puppets, prosthetics) that show a very high level of human-likeness generate a negative feeling instead of attraction (MacDorman, Green, Ho, & Koch, 2007). Figure 1 shows the original representation of the UV (Figure 1a), and our second simplified version (Figure 1b) displaying only the section of "still entities" and indicating the attraction (rather than the term "familiarity") in observers and the level of human-likeness. In the UV, stuffed animals and humanoid robots are placed at the top of the first peak and a real, healthy person at the higher top of the second peak. A successful device has a somewhat humanlike appearance, but its "artificially manufactured" look generates pleasant visual attraction, whereas, in contrast, entities with either a very low or a high level of human-likeness generate a negative emotional reaction of "eeriness."

The literature review shows that studies involving the UV mainly centered on humanoid robots (Hanson, 2006; Walters, Syrdal, Dautenhahn, Te Boekhorst, & Koay, 2008) and graphic design characters (Schneider, Wang, & Yang, 2007). The innovation of this paper consists in the attempt (for the first time) to apply UV theory for prosthetic devices as a way of offering a wider view of the relationship between realism and enhanced levels of attraction in people.

One interesting issue about UV theory pertains to the accuracy of understanding of the real meaning of the wording. According to Mori, MacDorman, and Kageki (2012), the English translation of the UV in 1970 was not sufficiently accurate, and the translation of the original Japanese term "*shinwakan*" as "familiarity" fails to capture the full essence of Mori's original meaning. A more accurate translation would be "when the sense of synchrony falls apart" (Hsu, 2012). For clarity, in this research the term "familiarity" is substituted with the term "aesthetic attraction."

Uncanny Valley for Prosthetic Devices

In 1970 Mori developed the UV for robots and humanoid entities, and only one prosthetic device was included (a prosthetic hand, which was placed at the bottom of the valley—Figure 1a). Our assumption in this research is that different kinds of prosthetic designs can be placed all over the UV graph according to their human-likeness and attraction level. In accordance with this statement, it is proposed to compare:

1. Industrial robots to prostheses with a clearly artificial appearance and a low level of human-likeness—i.e., non-human limb shaping, no skin color, no skin texture, no presence of details such as fingers, toes, nails, veins or hair (Figure 2a).
2. Humanoid robots to prostheses with human resemblance, but not too similar to human limbs, i.e., devices that would be clearly identified as a work of design and would never be confused with real parts of the body. For example, as a general guideline, we can list characteristics such as human limb shaping and proportion, optional presence of fingers or toes, no presence of details such as skin color, skin texture, nails, veins or hair (Figure 2b).
3. Robots that are "very human-like in appearance" to all prosthetic devices that are endowed with a very high level of human resemblance (Figure 2c). An example of a robot that could fall within the "Uncanny Valley" is the design by Hiroshi Ishiguro (2012), a professor at Osaka University (Figure 2d). A prosthetic device to be compared to this type of robot should present characteristics such as human limb shaping, presence of fingers and toes, and presence of details such as skin color, skin texture, nails, veins or hair.

Devices of the Third Area—with a very high level of human-likeness (Figure 1b)—cause a negative feeling in observers and fall into the trough of the "Uncanny Valley" (Figure 2c). We believe that the "problem" is that the look of these devices

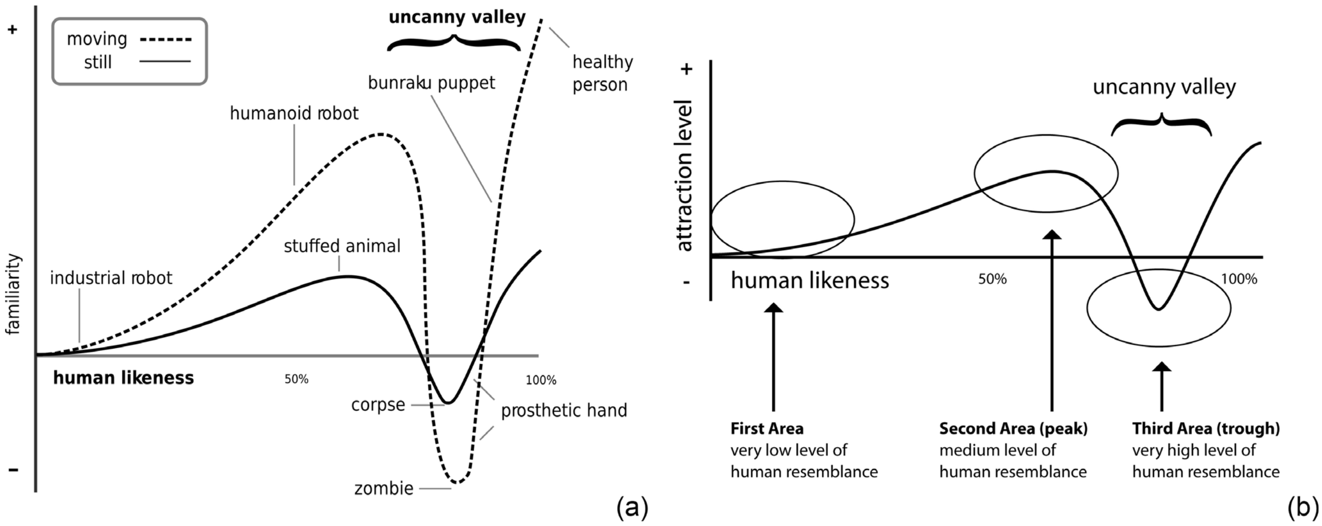

Figure 1. (a) The original version of the Uncanny Valley and (b) a graph highlighting the three areas where entities such as robots and a prosthetic hand are placed according to the visual attraction that they generate in people.
Graph edited to show only the "still entities" line.

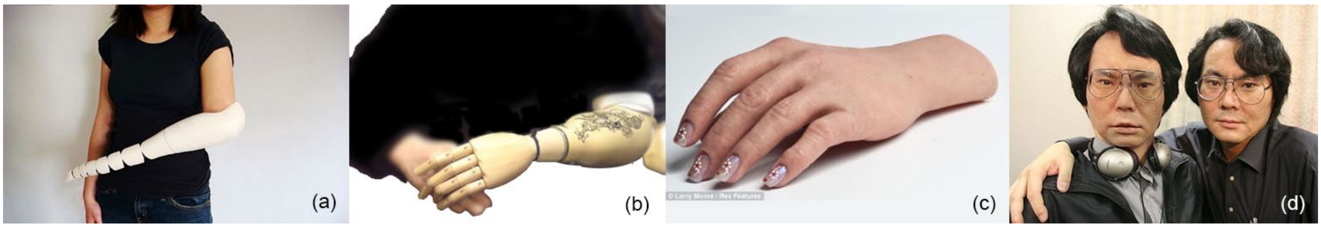

Figure 2. Examples of UV prosthetic devices and a robot: (a) artificial prosthesis with a low level of human-likeness (First Area, Figure 1)**; (b) device with medium level of human resemblance** (Second Area, Figure 1)**; (c) realistic device showing a high level of human-likeness** (Third Area, Figure 1)**; and (d) realistic robot with a high level of human-likeness** (Third Area, Figure 1)**.**

is *too* real, and consequently they create a sense of strangeness and generate a negative feeling. Prosthetic devices with a very low level of human resemblance (First Area, Figure 2a) should generate neither a pleasant sensation of visual attraction nor a creepy feeling as with devices falling into the trough. Our idea is that devices of the Second Area (Figure 1b), or rather devices that should be perceived as creative limb designs (Figure 2b), are the prostheses that should generate a higher level of attraction in observers.

As previously mentioned, the UV is particularly relevant in the creation of computer graphics (CG) characters, and consequently has been a topic of interest for CG designers. Non-realistic characters—for instance, The Simpsons (© Fox, Matt Groening) or Anime characters—are appreciated by a large audience as their anatomy suggests human resemblance, but they are clearly different from real actors (Nieters, Ivaturi, & Ahmed, 2007). Conversely, as stated by Levi (2004), the characters of the movie *Polar Express* (© Warner Bros Entertainment, Figure 3a) might not be perceived as convincing as they have a high level of human-likeness and risk generating a sense of strangeness. Similarly, the characters of the video game *Heavy Rain* (© Quantic Dream, Figure 3b) are even more human-like and are mentioned by Ho and MacDorman (2010) as examples of realistic characters embedded within the UV. They state that the UV may generate a feeling of strangeness and not generate attraction.

As well as supporting arguments, the literature also contains criticism of the UV theory (Brenton, Gillies, Ballin, & Chatting, 2005; Geller, 2008), with some authors stating that there is not enough evidence that the UV exists and that "some care is needed in the evaluation of claims about the UV until a more rigorous understanding is reached" (Pollick, 2010). Hanson et al. (2005) argue that highly realistic-looking robots and artifacts can appeal to people, rather than generating repulsion as stated by the UV. For instance, the authors propose examples of realistic art works (e.g., the sculptures of Ron Mueck, Figure 3c) as tolerated and respected by the audience. Additionally, the authors directly questioned the existence of the UV by a test showing a set of human-like robots to participants who then provided results that contradicted it. Aligned with this statement, Hanson (2006) argues that the contemporary concept of "human realism" should be redefined, because, for example, the concept of "highly realistic" devices of the 1970s (when the UV was first highlighted) is clearly different from the understanding of this concept nowadays.

In opposition to these statements, the basis of this work is that the UV does exist, and that its guidelines can be applied to prosthetic devices.

Personal Characteristics Influencing Aesthetic Attraction

The literature shows how products can emotionally influence people. The field of Emotional Design shows that people are likely to accept and make use of products that enhance their own positive emotions (Coates, 2003; Norman, 2004) and that these emotions might arise differently accord to the peculiarities of each person. For instance, Brinkman and Fine (2005) tested how personal characteristics of people (mainly connected to personality traits) influence their attraction towards the interface skin of programs.

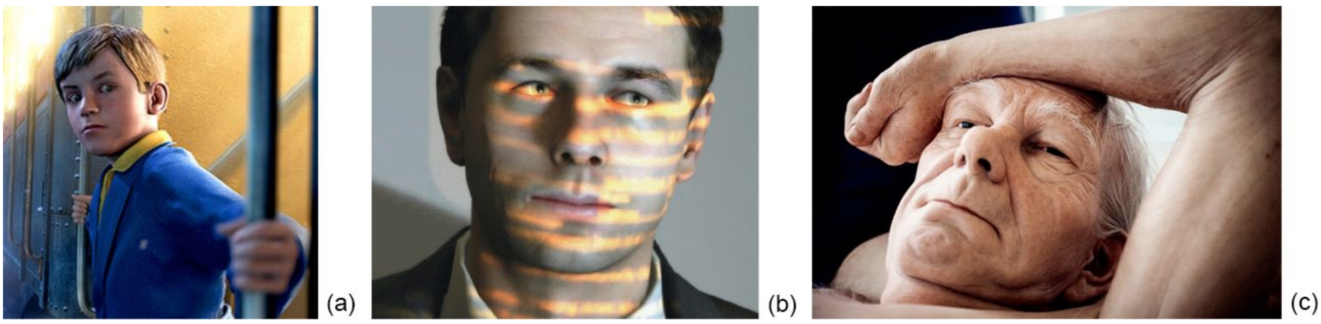

Figure 3. Realistic characters may generate an unpleasant feeling: (a) the animated movie *Polar Express* (© Warner Bros) **and (b) a screenshot of the videogame *Heavy Rain*** (© Quantic Dream)**; whereas an exception may be identified in (c) the highly realistic-looking sculpture by Ron Mueck *Couple under Umbrella*** (2013, detail, photo by T. Salva)**.**

Accordingly, we believe that emotional design accounts for the personal preferences of different users towards visual entities. This research aims to examine what levels of influence personal characteristics have in aesthetic attraction and to gain a rational understanding of which factors determine attraction to prosthetic devices. Relevant areas of interest examined in this article include gender differences (Salkind & Salkind, 1997) and cultural variations (Miller, 1973). These topics were selected for this paper from within a wider range of variables included in the main data collection (including participant age, education, occupation, economic situation, physical somatotype and personality) which were rejected as they did not achieve statistical significance in aesthetic attraction towards design.

Gender

Gender difference in aesthetic perception is an established factor. For instance, art perception differs between boys and girls due to their psychosocial variables (Salkind & Salkind, 1997). According to the results of the Welsh Figure Preference Test applied by McWhinnie (1970, as cited in Salkind & Salkind, 1997, p. 248), "males had a significantly higher preference for complexity-asymmetry." An investigation concerning girls' and boys' preference towards children's web sites shows, similarly, that boys were likely to give their preference to higher levels of visual complexity and girls to lower levels of visual complexity (Wang, 2013). Likewise, Savarese and Miller (1979) found that girls preferred "linear and painterly styled artworks." A study investigating the Five Factor Model (FFM) personality traits of Neuroticism and Agreeableness in elderly people showed that women scored more than men in Aesthetic Interest (Chapman, Duberstein, Sörensen, & Lyness, 2007).

Visual differences between genders may be traced to differing development of visual and spatial perception caused by different experiences in early childhood (Salkind & Salkind, 1997). This connection between visual and spatial perception arises because the task of disassembling and finding visual cues is a task similar to viewing works (Baenninger & Newcombe, 1995).

Differences between genders in the aesthetics of body appearance are well represented in the biology of the natural world. In many species, aesthetic differences between males and females allow for immediate recognition; for example, many males are distinguishable by the presence of gaudy colors and striking body details. Examples are *Phylloscopus* (Marchetti, 1993), guppies (Pocklington & Dill, 1995), yellowhammers (Sundberg, 1995), and gorillas (Schaller, 1976). Females of these species are endowed with lighter pigmentation and a more neutral appearance. The reasons for these differences reside in the fact that males need to attract the attention of females for procreation, and to intimidate opponents or predators.

This mix of physiological and psychological factors makes gender differences an appropriate factor to monitor in terms of preferences in prosthetic design.

Cultural Influence

Previous studies that have investigated cultural differences in aesthetic perception include that of Ji, Peng and Nisbett (2000), which states that people belonging to the same culture presented consistent similarities and differences compared with people from another country. The specific case in the article compared American and Chinese populations on environmental cognition.

It has been stated that, as a consequence of a process of social comparison with an evolutionary basis, people are influenced by the values and choices of the society to which they belong, and by their social class (Walker, Ehlers, Banerjee, & Dugundji, 2011). As an example of cultural influence we find differences in emotional perception of colors. Consistent correlations between colors and preferences in people of the same nationality, and differences between people belonging to different countries, are presented by Adams and Osgood (1973). Their study, conducted on 23 groups of 35 people, analyzed people's different perceptions of and levels of familiarity towards colors. In 2000, the "liking ratings" of people from Austria, Brazil, Canada and Columbia were tested with regard to colors for brand design (Madden, Hewett, & Roth). Each national group endowed the colors with different meanings.

Does a person's cultural background influence their emotional perception of a color, and can this principle also be applied to the pigmentations of prostheses? Consistent differences exist in color attraction or non-attraction from people belonging to different countries, and we believe this may also be relevant to prosthetic devices.

Method

The study consisted of an online questionnaire, taking approximately 25 minutes to complete, based on a set of closed questions structured mainly around a five-point Likert scale rating system for the two main outcome variables, human-likeness and visual attractiveness. The choice of a quantitative method was due to the necessity of collecting a large amount of data. The main section of the questionnaire asked participants to rate the attraction and human-likeness levels of a set of 30 images of prosthetic devices. The two questions asked regarding each image were: "Do you like this device?" and "Does it look like a real limb?" These aimed to test the levels of attraction towards the device and the participant's perception of the human-likeness level of each device.

The participants had, for each question, options ranging from 1 = not at all to 5 = yes, a lot. Thus high scores indicated higher levels of human-likeness and visual attractiveness. The aim of the first question was to verify the existence of the Uncanny Valley for prosthetic devices. The second question attempted to establish the human-likeness perception of the participants for the allocation of the devices to different Areas of the UV. As no prior study exists concerning the UV and prosthetic devices, the researcher did not find any "Uncanny Valley" scale for prosthetic devices and therefore had to design one independently. Other demographic questions were asked, not all of which are reported here.

Pilot Study

The content and face validity of the study were assessed by using a pilot study questionnaire and collecting 12 responses, 11 from non-amputees and one from an amputee. The non-amputee respondents had experience of questionnaire design, were experts in evaluating the Likert scale system, or had knowledge of prosthetics. The amputee participant's identity was kept totally anonymous and was included for feedback from a prosthetic user's perspective, thus establishing face validity. Each respondent acted independently when completing the questionnaire and when supplying their feedback. Feedback from the pilot was used to amend the main study, clarifying the wording and making the questions as clear as possible for people with different educational and language backgrounds.

Participants

Non-amputee participants were recruited through an advertisement posted on the Internet webpage of the University of Strathclyde's undergraduate and postgraduate students' network (using the student website, social networks, and e-mail). Amputees were recruited through an Internet advertisement published on the websites of amputees' associations. There were 114 participants in the study, and they can be classified as follows:

1. Amputation: Amputees 24 (21.1%); non-amputees 90 (78.9%).
2. Nationality: UK nationals 26 (22.8%); Italian nationals 60 (52.6%); nationals of 15 other European Union (EU) and 13 non-EU countries 28 (24.6%).
3. Gender: Male 46 (40.4%); female 68 (59.6%).

Amputee participants were sub-classified into: lower limb amputees 22 (92%) and upper limb amputees 2 (8%); the percentage of lower limb amputees was considerably higher than upper limb amputees. We considered that there were similar risks between lower limb amputees not being familiar with upper limb designs, and upper limb amputees not being familiar with lower limb designs, and this was the risk that we might only get an objective evaluation of the prostheses deemed suitable for their own particular circumstances. Naturally, there was also a risk that non-amputees might not be familiar with prosthetic designs, and this factor might have influenced the level of attraction stated in the questionnaire. These issues must be considered as a limitation of our research, as the researchers did not have the opportunity to test the statements, or to ascertain whether the issues caused any inaccuracy in the results of the study.

Uncanny Valley

To test the UV, 30 images of prosthetic devices (D1, D2, ..., D30) were selected from the Internet and edited in Adobe Photoshop© in order to achieve 1) standard visible size of the prostheses (not to be confused with the size of the whole picture), and 2) standard neutral background. The sizes of the pictures varied according to the sizes of the prostheses on show; for example, images showing small prostheses were slightly enlarged to enable clearer viewing. The images had consistently neutral backgrounds, demonstrated use of the prosthetic, and were presented in a set of visually consistent slides with any extra recognizable details of the wearers obscured, so as not to influence the evaluation of the participants (Figure 4).

The UV was tested by showing a set of images of prosthetic devices with different levels of human-likeness corresponding to the three Areas showed in Figure 1b. Considering that no work so far has specifically involved the level of human-likeness for prosthetic devices, the criteria for division of the images into each category was developed by the authors, who had extensive experience in the area.

Ethics

The study was reviewed and approved by the University Ethics Committee of the University of Strathclyde.

Data Analysis

The reliability of the questionnaire was assessed using Cronbach's alpha for the internal consistency of the sets of responses to each of the two main outcome variables within each Area. The outcome variables, human-likeness and visual attractiveness, were summarized numerically for each image (D1, D2, …, D30) and for each Area of human-likeness.

The attractiveness and human-likeness Area data were analyzed using repeated measures ANOVA models with Greenhouse-Geisser correction factors. Tukey's post-hoc test with adjusted p-values was used when required. Initial models introduced the between-subject factors of Gender (2 levels), Culture (3 levels) and Amputation (2 levels), but these were dropped if non-significant.

All main analysis was performed on SPSS v22 with MS Excel for figure construction. The level of significance was set at 5% for all hypothesis testing. The analyses of other demographic variables collected during the survey are not reported in this paper.

Results

Of the 165 responses obtained, 114 (69%) were valid for use. The responses that were removed either only supplied demographic data, or only a minimum set of responses, and hence were not suitable for analysis.

Summary Statistics and Internal Consistency of the Questionnaire

Prior to any calculation of Area responses, it was confirmed that the areas themselves formed appropriate groupings and that hence image scores could be combined. Table 1 summarizes the attractiveness and human-likeness responses to each image, the Cronbach alpha values for each Area, and the mean and standard deviation values by Area. All Cronbach values were above 0.70 and hence considered acceptable. Dropping each image in turn within each Area grouping did not indicate an improvement in the alpha values, hence the analysis is based on all 30 images in the Areas defined in Figure 4. Figure 5 illustrates the Area comparisons for attractiveness and human-likeness.

Figure 4. Devices shown in the questionnaire along with the authors' classifications proposed in Figure 1b.

Table 1. Summary statistics by Image and Area and Cronbach's alpha for each Area.

Device Image	*Attractiveness Mean (sd)*	*Human-likeness Mean (sd)*	*Cronbach's Alpha*
D1	3.25 (1.13)	1.98 (0.99)	
D7	1.94 (1.00)	1.46 (0.59)	
D10	2.90 (1.31)	1.67 (0.60)	
D22	2.23 (1.04)	1.63 (0.64)	
D23	2.02 (1.11)	1.48 (0.59)	
AREA 1	2.47 (0.78)	1.64 (0.48)	Attractiveness 0.72 Human-likeness 0.73
D2	3.75 (0.88)	3.28 (0.95)	
D3	2.96 (1.08)	2.88 (1.17)	
D5	3.83 (0.93)	3.55 (0.99)	
D8	2.89 (0.88)	2.93 (0.78)	
D9	2.93 (1.13)	2.17 (0.86)	
D11	3.24 (1.08)	2.56 (0.97)	
D15	3.16 (1.11)	2.46 (0.93)	
D16	2.96 (1.13)	2.37 (0.81)	
D17	2.41 (0.91)	3.24 (1.02)	
D20	2.44 (1.10)	2.09 (0.71)	
D25	2.70 (0.98)	3.26 (0.99)	
D26	3.58 (0.04)	2.79 (1.07)	
AREA 2	3.14 (0.50)	2.89 (0.54)	Attractiveness 0.74 Human-likeness 0.84
D4	3.32 (1.05)	4.04 (0.85)	
D6	4.15 (0.79)	4.69 (0.50)	
D12	4.01 (0.90)	4.50 (0.74)	
D13	4.16 (0.80)	4.70 (0.57)	
D14	3.78 (0.80)	4.31 (0.71)	
D18	2.96 (0.92)	3.62 (0.91)	
D19	3.56 (0.93)	3.98 (0.87)	
D21	3.25 (0.97)	3.84 (0.96)	
D24	3.30 (0.93)	3.91 (0.95)	
D27	3.76 (0.91)	4.41 (0.66)	
D28	4.07(0.80)	4.57 (0.52)	
D29	3.45 (0.93)	3.97 (0.76)	
D30	2.66 (0.87)	2.96 (0.92)	
AREA 3	3.57 (0.63)	4.13 (0.48)	Attractiveness 0.92 Human-likeness 0.86

Both Table 1 and Figure 5 clearly indicate a gradual increase in average score across the three Areas and it is also apparent that for Areas 1 and 2, attractiveness achieves a higher rating than human-likeness, but for Area 3 this pattern is reversed. The correlation between levels of attractiveness and human-likeness increases from 0.273 to 0.429 from Area 1 to Area 3, thus from a small effect to almost a large effect. Table 2 illustrates the levels of attractiveness and human-likeness, summarized by Gender, Culture and Amputation.

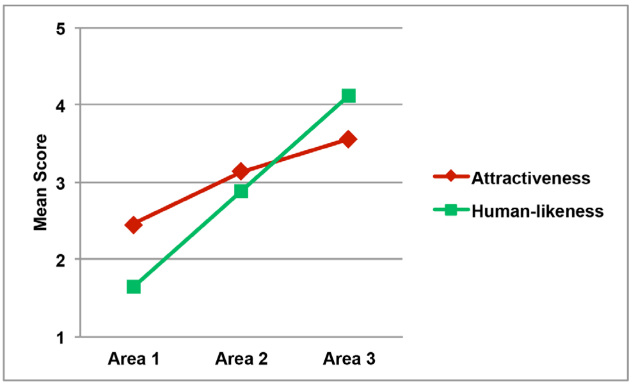

Figure 5. Mean scores by Area.

Table 2. Summary statistics by Gender, Culture and Amputation.

	Gender		*Culture*			*Amputation*	
	Male	Female	Italy	UK	Other	No	Yes
	Mean (sd)		Mean (sd)			Mean (sd)	
Area 1							
Attractive-ness	2.69 (0.77)	2.43 (0.70)	2.43 (0.72)	2.94 (0.73)	2.32 (0.64)	2.46 (0.71)	2.82 (0.78)
Human-likeness	1.69 (0.24)	1.69 (0.46)	1.81 (0.45	1.44 (0.31)	1.69 (0.55)	1.76 (0.48)	1.38 (0.26)
Area 2							
Attractive-ness	3.23 (0.47)	3.09 (0.51)	3.13 (0.49)	3.29 (0.56)	3.04 (0.42)	3.09 (0.49)	3.40 (0.46)
Human-likeness	2.82 (0.54)	2.92 (0.54)	2.99 (0.55)	2.64 (0.51)	2.91 (0.51)	2.93 (0.54)	2.68 (0.51)
Area 3							
Attractive-ness	3.36 (0.55)	3.69 (0.63)	3.68 (0.57)	3.39 (0.63)	3.47 (0.68)	3.60 (0.62)	3.38 (0.60)
Human-likeness	4.01 (0.43)	4.22 (0.48)	4.11 (0.46)	4.15 (0.41)	4.17 (0.56)	4.13 (0.48)	4.15 (0.45)

Attractiveness averages higher than human-likeness for both males and females except in Area 3, and it is also in Area 3 that the pattern within each of the three demographic variables tends to change. For example, for attractiveness Italy now has highest mean and for human-likeness Italy has the lowest mean.

Area Analysis

Attractiveness

The repeated measures ANOVA model across the three Areas resulted in a very significant Area effect ($p < 0.001$). The between-subjects factors of Gender, Culture and Amputation were initially included in the model, but only Gender was found to be significant ($p = 0.001$). This Gender effect appeared to be due mainly to the Area 3 difference (Figure 6) and the small standard deviations.

Post-hoc testing for the main factors indicated that all three Areas were significantly different from each other, each with adjusted p-values of 0.001. Subsequent within-Area analysis revealed no significant Culture effect in any Area, a Gender effect in Areas 1 and 3 ($p = 0.013$ and 0.005 respectively), males on average higher in Area 1 but lower in Area 3 and an Amputation effect only in Area 2 ($p = 0.015$), with amputees scoring higher on average. On average, only for Area 3 did females rate attractiveness higher than males.

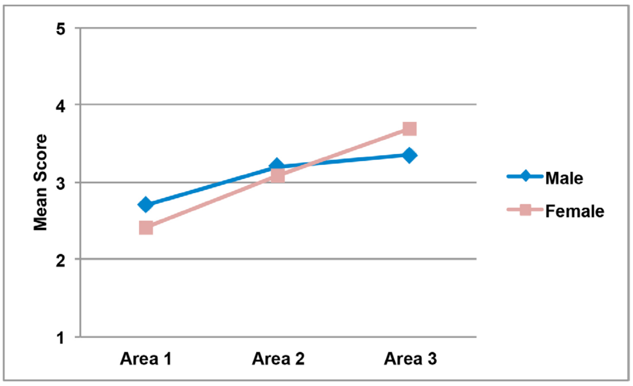

Figure 6. Mean attractiveness by Gender and Area.

Human-likeness

A similar model was used to analyze the human-likeness mean score by Area and once again a very significant Area effect was found ($p < 0.001$), but no between-subject factors were significant. The post-hoc analysis confirmed that all three Areas were also significantly different from each other with respect to human-likeness, all with $p = 0.001$.

Subsequent within-Area analysis revealed significant Cultural effects in Area 1 ($p = 0.006$) and in Area 2 ($p = 0.039$) but not in Area 3 ($p = 0.601$), with the UK being significantly higher than Italy in both Areas ($p = 0.004$ and 0.030 respectively). A very significant Gender effect was found for Area 3 ($p = 0.006$), with females being significantly higher, and an amputation effect was found in Area 1 ($p < 0.001$), with non-amputees scoring significantly higher.

Discussion

Uncanny Valley for Prosthetic Devices

The results from the questionnaire show that there is accord between the responses on the level of human-likeness and the authors' categorization. This data evidences that the division criteria applied by the researchers were accurate and that participants had a realistic understanding of the level of realism of the devices. Consequently, it can be affirmed that the devices chosen for the questionnaire were suitable for meeting the aims of the experiment.

Regarding the attractiveness ratings, the results did not support the research expectation. Artificial devices with a low level of human-likeness (Area 1), similarly to the UV of Mori, received, as expected, a very low attractiveness rating in comparison to medium-realistic devices (Area 2). However, the Area 3 devices had been expected to be less attractive than those in Area 2, yet they received the highest rating. Thus the highest level of attraction was attributed to very realistic prosthetic devices (Area 3), where the level of human-likeness had the strongest correlation to the level of attraction. In other words, the more realistic devices are, the more people appreciate them.

Following these findings, the principal observation that we record is that the Uncanny Valley conceived by Mori does not apply to the aesthetics of prosthetic devices. There may be multiple reasons for this result. Our first observation is that, as previously stated, the UV is an old theory of the 1970s and has not been fully tested and verified more recently. Additionally, the level of realism of prosthetic devices and humanoid robots has greatly improved in recent years. Consequently it might be the case that people are now exposed to them by the media and have been getting used to these designs: this development might have had a positive effect on the visual appreciation of highly realistic devices. Therefore, the UV cannot any more be thought of as a reliable theory to apply to the aesthetics of human products or robots; perhaps the UV might have been considered applicable 40 years ago, rather than to the designs and the audience of today.

We speculate that nowadays the "uncanny" unpleasant feeling may be found only with prostheses resembling other sections of the body that are more intimately connected with the "identity" of the wearer, such as facial prostheses (like a silicone nose), and that this rule may apply also to the facial design of robots and graphic characters.

An alternative explanation of the findings might be found in one limitation of our investigation, the fact that the source of the data (screen images) was not appropriate. People might not have felt unpleasant feelings because the screen image could have misled the observer as to the degree of "artificiality" of highly realistic devices. In other words, our supposition is that most of the participants felt attraction rather than creepiness because their visual perception could have suggested that the images of prostheses were not artificial, but actually real limbs.

We speculate that devices such as D6, D12, and D13 could have been placed at the bottom of the valley rather than at the top of the second peak of the graph if the observers had been exposed to a more realistic visual perception of these products (i.e., seeing the real 3D prosthesis). This idea is supported by the fact that highly realistic devices showing a detail of artificiality (e.g., band for attachment to the stump—D18, or color gradation different from that of the skin of the wearer—D25), received lower mean levels of attraction.

Attraction to Prosthetic Devices: *A New Perspective*

After observing the results, we present a new graph representing the relation between attraction and human-likeness perceived by participants, in which the line of the graph follows the main ratings of the devices as per the participants' scores (Figure 7). Rather than the Uncanny Valley, this graph shows a growing attraction for increasingly human-like devices, with a small dip (instead of a "valley") for devices closely resembling a limb but showing creepy artificial patterns.

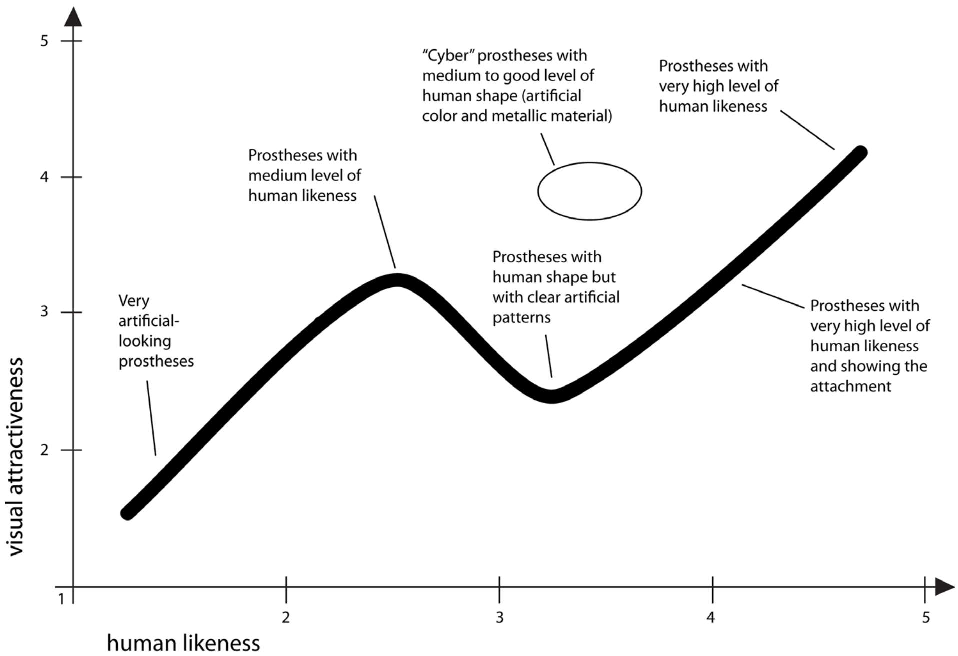

Figure 7. "N shaped" relationship between attraction and human-likeness for prosthetic devices.

The graph demonstrates that the first depression area, generating a lower level of attraction, includes devices showing a very low level of human-likeness (e.g., D23 and D7). A significantly higher level of attraction is found at the first peak of our graph, which includes devices with a medium level of human-likeness. Specifically, these devices have the following characteristics: (a) they resemble the anatomical shape of human limbs, (b) they are made up of materials that appear metallic, and (c) they incorporate at least two colors.

The trough of the graph encloses all the devices that start to have more realistic human-likeness patterns than the previous two Areas and that (a) follow more detailed anatomic shapes, (b) have a color closer to human skin pigmentation (but not perfectly identical) and (c) have evident details of artificiality (e.g., a puppet aesthetic look). The graph's final upturn covers devices that are closer to looking like real limbs. Devices that look more real, but still show patterns of artificiality (e.g., D18 and D21) are placed at the bottom of the rising line, where the devices that start to look more realistic rate a higher level of attraction.

The devices placed at the top of the second peak are devices that could easily be mistaken for real legs or arms, and include characteristics such as (a) high levels of resemblance to human proportions, (b) high levels of resemblance to skin color (the material used is high definition silicone or PVC), and (c) the presence of body details such as nails, veins, knuckles, tattoos, and nail polish.

The ellipse placed at the top above the trough represents an unexpected Area. The two devices placed here recorded a high attraction level but did not correspond with the aesthetic appearance of the devices of the second peak. They can be described as being (a) cyber-robot looking; (b) endowed with medium-high levels of human anatomical proportions, (c) made of metallic material, and (d) of a uniform silver color.

Exceptions and Additional Observations

In relation to the findings reported in the "N-shaped" graph, we found three devices representing exceptions:

1. D1 and D10 are the lower limb devices of Area 1, placed in the first depression Area; they received a higher attraction rating than the upper limb devices of the same Area. Further characteristics common to D1 and D10 are that they are devices designed for sporting activity, and that both of them are endowed with gaudy pigmentations (in D1 only on a section, whereas D10 is entirely colored). Working out why these devices were rated differently than the others is not straightforward. An article discussing the role of the media's and society's vision of disabled people (Tynedal & Wolbring, 2013) found that Paralympic athletes are seen as "superheroes"; the athletic performance of people with disabilities is strongly positively appealing to the public interest. Our idea is that participants in the experiment, which took place a few weeks after the London Paralympics 2012, might have been positively affected by the vision of devices designed to allow amputees to perform in a sport.
2. D24, according to its high level of human-likeness, was expected to be placed high on the second peak as generating a higher level of attraction. However, we should state that D24 is the only prosthesis in the experiment resembling a child's device, and we speculate that participants may have given it a lower attraction rating, as the idea of a child amputee may have generated an unpleasant feeling. Accordingly, we find that the literature shows that adults (in particular, parents) find it easy to imagine, and demonstrate preoccupation with, the social consequences of the disability of a child (Racy, 1989), as well as the aesthetics of the prostheses (Hilhorst, 2004).

In the following section we review the role of personal characteristics of the participants in relation to their attraction to the level of realism in devices.

Gender Differences in Attraction to Devices

The statistical findings show that male participants were more attracted to devices belonging to Areas 1 and 2 (i.e., robotic-looking devices and devices with a human resemblance but with clear artificial patterns). The devices generating attraction in female participants belonged to Area 3 (i.e., devices with a very high level of human resemblance).

It is our view that prostheses from Area 3 might be considered a discreet choice for limb replacement, for instance by people who wish to avoid attracting the attention of observers, as they believe that the difference between the prosthesis and a real limb is not readily noticeable. Devices from Areas 1 and 2, on the other hand, are endowed with patterns suggesting visual artificiality (D1, D2) or striking designs (D10) and observers might appreciate the fact that these devices do not faithfully reproduce the limbs they are intended to replace and represent non-conventional and original designs.

Male preferences towards robotic devices may exist because of the "masculine" patterns embodied by these designs. Weitz (1998) states that people endorsing the image of a "muscular and mature" character (masculine behavior) want to create an image of "strength, power and violence." Female statements of attraction for "neutral" and "graceful-looking" prostheses are aligned to findings about differences in self-perception between genders (Oumlil & Erdem, 1997), where it was found that women "would like to see themselves as more graceful… than male respondents."

We suggest that the origin of the difference between genders may reside in an innate attraction towards features, whereby a masculine product identity (e.g., gaudy colors and striking designs) may attract male observers, and features suggesting feminine and graceful appearance (e.g., natural skin colors and harmonic human shape) may appeal to female observers.

This statement is in contradiction to the belief of Ho, MacDorman, and Pramono (2008), who found that women, in relation to the UV, were more "sensitive to eerie and creepy [realism in robots] than men." Similarly, the declarations of the top model and double amputee Aimee Mullins regarding her set of artistic prostheses, conceived as fashion accessories (Vainshtein, 2012), clearly show that women can show a positive interest in non-realistic prostheses. However, in contrast with these two pieces of evidence and in accordance with our findings, the literature shows that female users are supposed to prefer cosmetic–realistic designs (Murray, 2009) and that consequently, we assume, they might not be affected by the UV "creepy" feeling of realism. The preference for these devices could be simply due to the desire for using feminine accessories and clothes (Nguyen, 2013), or due to female amputees suffering more than males from society's visual expectations of their body appearance (Gallagher, Desmond, & MacLachlan, 2008), so that a device that does not immediately show the disability can be considered a better option.

We advise, as a general guideline for prosthetic design, that preferences in design towards realistic-looking prostheses for women (Area 3), and artificial-looking prostheses for men (Areas 1 and 2) may exist. However, this conclusion represents only a hypothesis and needs further investigation. The authors plan to explore this issue by displaying during a future interview a set of prosthetic devices endowed with realistic and robotic features to male and female participants, and to explore whether the motivations that lie behind their choices correspond to our hypothesis.

The Effect of Cultural Differences on Attraction to Devices

Italian participants, compared to UK participants, registered a slightly but non-significantly higher level of attraction towards some devices with a high level of human-likeness (belonging to Area 3—Figure 4). Italian culture is particularly attuned to fashion and, specifically, we observed that the idea of elegance encourages the choice of meticulous style and discreet color combinations. For instance, black is considered a standard choice, suitable for combining with natural-looking/neutral colors (e.g. brown) or for use on its own.

The authors hypothesize that Italian participants may have perceived highly realistic devices as appealing because they were natural in appearance, and there was no striking difference between the features of a real limb and the prosthesis. The contrast between a real limb and the prostheses of Area 2 might have been considered not particularly attractive as they were unnatural in appearance. The exception of the only device of Area 2 generating attraction in Italian participants is D3. The presence of smooth and curved metal slats and a gently shaped wooden frame gives the device a touch of elegance and sophistication and it might have been the pattern that generated the attraction.

British culture, in contrast, arguably does not seek elegant fashion in the Italian sense. British society encourages more freedom of choice and individual taste, and the specific use of bright and colorful clothes is appreciated. Considering the factor "color," Geboy's (1996) comment that color combinations are considered culturally bound with certain ideologies and traditions provides an explanation of the fact that color preference can be influenced by society. The preference for devices D10, D11, and D26 is not accidental—these three devices are the more colorful prostheses of the set. Consequently, we state that the use of bright colors associated with alternative stylish design may be connected to the understanding of UK fashion.

Regarding the factor of cultural influence for UV perception, Brenton et al. (2005) state that the constant interaction of people of the same culture with realistic avatars might influence (make them avoid) the uncanny feeling towards them. Similarly Gee et al. (2005), when revising the traditional vision of the UV, suggests that factors such as age, religion and culture influence how the UV affects people.

The authors suggest that Italian culture may favor more natural-looking and sophisticated shapes in prosthetic design, while British culture may encourage the choice of more non-conformist and gaudy designs. Further research is required in this area.

Amputation as an Influencing Factor in the Level of Attraction to Devices

Amputation was not a significant effect across Areas. However, within Area 2 amputees scored attractiveness significantly higher than non-amputees, and in Area 1, amputees scored human-likeness significantly lower than non-amputees. The devices belonging to the First and more specifically the Second Area (Figure 4) were slightly more appreciated by amputees than by non-amputees. This data suggests that most amputees do not confirm the UV and express attraction to devices with an interface dissimilar to a real limb. From this point we deduced that there might be a characteristic in amputees that leads them to be attracted to non-realistic devices. We suggest that this factor (not investigated by the questionnaire) could be the length of time since amputation.

We speculate that the level of acceptance of amputation is related to the preference for cosmetic or robotic devices. Specifically, rejection of realistic devices (Area 3) would be found, it is suggested, only in amputees who had fully accepted their loss of limb(s), whereas attraction to realistic prostheses would be found in amputees who are in the early stages after amputation and so have not fully accepted their loss of limb(s). Amputees who have gained a psychological acceptance of their amputation may therefore prefer devices located in the first peak of the Valley (Area 2). Conversely, amputees who have not (yet) gained psychological acceptance of their loss of limb(s) may prefer devices located at the bottom of the Valley (Area 3).

Consequently, the advice of the researchers is to take into account the length of time since amputation. This period might influence the level of acceptance of the new body image and, consequently, the choice of a device that resembles a real limb (or does not). This finding is not supported yet by evidence and represents only our explanation of the findings. However, our idea will be further investigated in a future experiment based on an interview.

Conclusion

The data obtained in this paper show that the three Areas representing different levels of human-likeness of prostheses settled by the authors before the experiment were perceived in different ways by the participants. Therefore, we could state that our criteria of division, which consist in identifying the presence or absence of certain patterns (e.g., toes, skin color) are validated.

The variation in the strength of the relationship between human-likeness and attraction to prosthetic devices demonstrates that the original version of the UV is not applicable to modern prosthetic devices, as the attractiveness of realistic models was rated significantly higher than that of robotic-looking devices. The first section of our revised UV graph for prosthetic devices (described as "N-shaped") encloses prostheses with a medium level of human-likeness; the last section encompasses devices with a high level of human resemblance; in the middle lie realistic devices with artificial details, falling into a small "dip in attraction." The categories of participants that were tested to verify differences in attraction included people divided into groups by gender, nationality and presence of amputation; however, in the main analysis, a statistically significant difference was found for gender only, while factors such as nationality and amputation registered minor differences. Thus it can be stated that the conclusions for these two variables need further future validation.

Males were found to be more attracted towards non-realistic devices rather than realistic models, whereas female participants recorded more appreciation for realistic devices. Factors that generate attraction of males towards robotic devices may include the "masculine" patterns of the product, for example robotic appearance, gaudy colors, and sharp shape; while females had preferences for realistic-looking devices, attracting less visual attention to the missing limb. This difference in prosthetic attraction may reside in an innately different color preference, in the social pressure on females' appearance, or in the better combination of feminine accessories with realistic devices rather than with robotic-looking devices.

It was shown that both British and Italian participants stated an attraction to non-human-looking devices, and that while Italians reported attraction towards realistic prosthetic devices, British people were slightly more attracted towards certain robotic and gaudily colored devices. This difference might be due to a cultural difference in color appreciation, and also to a different cultural understanding of what constitutes good fashion style.

A percentage of amputees expressed a higher level of preference for a few robotic-style (non-human-like) devices. This data can be connected to the influencing factor of a higher level of familiarity in amputees. However, an additional relevant observation is that the length of time since amputation may also be an influencing factor. It could be hypothesized that the stage of acceptance of the amputation might be related to the preference for cosmetic or robotic devices: people with a longstanding amputation might have developed a more mature understanding of their body shape and thus may not desire a prosthesis similar to their lost limb. This point is, however, not supported by any evidence and is still only a hypothesis needing further investigation in future research.

This research aims to help prosthetic designers to meet the individual needs of amputees. The intention of the authors is to provide useful guidelines in order to improve future prosthetic designs and, as a consequence, to give more opportunities for amputees to achieve a positive feeling in relation to their prosthetic device. Visually successful prostheses may draw positive appreciation from amputees and, in helping to maintain a good self–body image, make the process of acceptance of the prosthesis easier.

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