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Utilising the Repertory Grid Technique in Visual Prosthetic Design: Promoting a User-Centred Approach

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Abstract This paper proposes a new User-Centred data-collection methodology based on the Repertory Grid Technique (RGT) for the aesthetic design of below-knee prostheses. The innovation of this methodology is to propose a measurable approach guiding the designer to detect latent emotional needs of interviewed prosthetic users to be translated into measurable aesthetic issues to reproduce in their customized devices. This work is situated within the Kansei Engineering framework and is part of a more comprehensive study for the revision of aesthetic prosthetic design. The data of this paper are based on face to face interviews and the results were translated into a set of design principles and elements classifying the statements of the users. This methodology aims to stand as an initiative for a new design system for the improvement of the emotional User Experience of prosthetic users – and to consequently provide products to be positively accepted by the users for the improvement of their body image.

Keywords: Prosthetics, Methodology, Visual Design, User-Centred Design, Design Principles

1. Introduction

Below limb prostheses are artificial devices designed to replace a missing limb for prosthetic users and are identified by our research as special and intimate products affecting the self-body image of the wearers. Our belief is that, accounting the importance for a device to feel comfortable to wear and functional to use, amputees also require visual appealing aesthetic in the devices to fulfil their emotional needs. Visual prosthetic design, which can also be identified as prosthetic form, is indicating the appearance of the products - or rather how the products look like.

Unlike the extended work to date on prosthetics which has largely focused on the technical improvement of the devices (Hahl, Taya, & Saito, 2000; Klute, Kallfelz, & Czerniecki, 2001; Mak, Zhang, & Boone, 2001), the field of research into aesthetic of prostheses is relatively new. Our search found few academic studies discussing realistic-appearance aesthetic devices and that the literature focuses mainly on upper limb designs (Biddiss, Beaton, & Chau, 2007; Davies, Douglas, & Small, 1977; Ferrone, 2001). This contrasts with a considerable number of companies (e.g. “Procosil”, “Touch Bionics”, “The Alternative Limb Project”, “Ottobock”) and associations (i.e. “Amputee Coalition”, “Amputee prosthetics”, “Westcoast brace and limbs”) that deal with the production and/or advertisement of high-level realistic-looking limbs. Similarly, we found little literature investigating the aesthetics of

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non-realistic devices (Capestany & Esparza, 2011; Hilhorst, 2004; Plettenburg, 2005), as well as few companies (e.g. “The alternative Limb project”, “Bespoke innovations”) and designers (i.e. Sophie de Oliveira Barata, Scott Summit). This suggests limited academic investigation of visual prosthetic design has taken place up to now, and that the research on non-realistic looking prostheses is particularly scarce.

As part of the lack of research in the field, we have been particularly concerned in the absence of an academic method for visual prosthetic design.

We believe that a robust methodology guiding the aesthetic design process would be extremely important for the manufacturing process for both public and private prosthetic centres. Our belief is that this procedure should guide the designer to provide the amputee with a customised option responding their personal needs.

In response to that, this paper proposes a new methodology for the aesthetic design of robotic below knee prosthetic devices and aims to provide a set of guidelines for the development of a user centred data collection approach for the improvement of the emotional user experience. In this work we propose a set of steps for the designer to understand the personal visual requirements of the user and focuses on the data collection process. The design of the methodology is based on semi-structured interviews; this chapter presents both the results of the data collection and a universal-applicable methodology approach.

1.1. Kansei for Visual Prosthetic Design

In considering the visual aspect of prostheses for below-knee devices, the models resembling the realistic appearance of a human leg are identified with the term ‘cosmetic’ (Fig. 1a and b), while ‘artificial’ prostheses identify devices with an appearance dissimilar to a human leg (**Error! Reference source not found.**c, d and e). Within artificial-looking models, we identify ‘robotic’ devices (**Error! Reference source not found.**d) as a distinctive design type from the uncovered design (**Error! Reference source not found.**c). Under our definition of ‘robotic’ we include devices making use of ‘fairings’ for the cover, or rather “intricately designed panels that fit over prosthetic legs - the fairings create a shell around the traditional prosthesis, giving the mechanical limb a more aesthetically elaborated solution” (**Error! Reference source not found.**d) and monolithic designs (**Error! Reference source not found.**e). Prosthetic models provided by the NHS prosthetic centres include only basilar design like devices of figure 1a and 1c.

As supported by the literature review (C. D. Murray, 2005; C. D. Murray, 2009; Nguyen, 2013) and our previous investigations (S. Sansoni, Wodehouse, & Buis, 2014), the standard prosthetic models currently offered within prosthetic centres might not meet the visual requirements of prosthetic users.

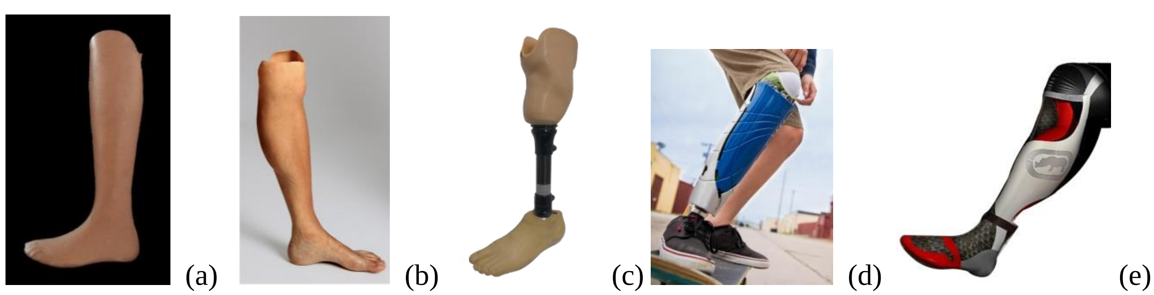

Fig. 1. Cosmetic foam-covered (author photograph) (a), PVC highly realistic (©2012Rosemary Williams) (b), basilar uncovered (author photograph) (c), robotic cover design (UNIQ, 2015) (d) and monolithic model (Jordan Diatlo design) (e) prosthetic devices

Our research conceives prostheses as emotional products. Defining prostheses in this matter is particularly appropriate considering that this kind of device is strictly related to the body image of a person with a physical impairment who may perceive the prostheses as a very intimate product. Accordingly to this vision, our research is inserted within Kansei Engineering. By considering the statements of Nagasawa (2004) the Kansei process cannot be measured directly, and what can be observed are the causes and consequences of the process. Between the gateways for detecting Kansei we identified an interview technique where people are asked to express their Kansei in words upon seeing products as method. The use of this gateway is supported by Jiao et al., who show that consumers can be guided to express their affective needs, feelings, and emotional states successfully by using Kansei adjectives (2006). Within the case of our specific investigation, the Kansei words have been measured by applying a technique within the Personal Construct Psychology (PCP), the Repertory Grid Technique (RGT).

1.2. Repertory Grid Technique

The PCP was originally developed by the American psychologist George A. Kelly to investigate people's understanding of the world within the field of psychotherapy (Kelly, 1955). The original aim of this interview-based technique was to help patients to understand how they see the reality, however this approach has been largely used in other context outside medical scrutiny to understand people's perception of images (Hankinson, 2004), where many market research groups investigating product perception made use of it (Hankinson, 2005; Lemke, Clark, & Wilson, 2011; McEwan & Thomson, 1989). The RGT is the operationalization of the PCP (Coshall, 2000) and involves recording data obtained during the interview in a grid-based quantifiable database.

The RGT consists in a semi-structured interview in which respondents are asked to choose and relate a triad of elements by describing the way two of them are alike and thereby different from the last one (Hassenzahl & Trautmann, 2001). The elements can either be chosen by the participants or by the interviewer. The characteristic of similarities and differences described by the respondent are *elements* and *constructs*, that represent the focal points of the technique (Coshall, 2000; Hankinson, 2004).

Elements are objects of people's thinking, and in the case of application for product design studies, the elements are a set of products that the designer aims to investigate the perception. In the case of our specific study, the elements are prosthetic devices.

The constructs are the personal interpretations of the interviewed of the elements. According to the description of Kerkhof (2011), the constructs are "the discriminations that people make to describe the elements in their personal, individual world". An essential characteristic of constructs is that they are 'bipolar' (e.g. cold−hot, good−bad)".

2. Method

The RGT has been used for our data collection by adaption its application to our experiment (see 'procedure'). The experiment aimed to discover the individual attraction of participants for their ideal prosthetic product. A set of 9 visual prototypes has been shown to each participant to detect a list of preferred aesthetic attributions to guide the final personalized design. The study consisted of open interviews that took approximately 45-60 minutes to complete.

The data collection took place over three months. The interviews were made individually, either face to face or through video-call. The researcher conducted the interviews by showing the 9 prosthetic models on screen by displaying the images and 3D videos of the visual prostheses in order to provide to the participants a clearer understanding possible of each design.

The video interviews were structured to be consistent with the face to face interviews. In order to gain objectivity, the researcher applied some expedients. For instance, participants were asked to use a wide monitor screen and test the audio was working properly and the good quality resolution of the shared screen for the visualization of the prostheses by asking the interviewed to describe if he/she could see and describe small details on the first and second model. The interviews were made in English, with exception for three Italian participants who asked the interview to be made in their mother tongue to make the communication easier.

2.1. Participants

The requirement for participating was to be a lower limb prosthetic user and to be over 18 years old. There were nineteen participants in the study. The sample of 19 participants had a mean age of 50.2 years [sd = 10.3, range 33 - 70] and consisted 84.2% [n = 16] males. The mean time since amputation was 11.5 years [sd = 13.3, range 1 – 53] and they came from 4 countries: 42.1% [n=8] Scottish; 31.6% [n=6] English; 15.8% [n=3] Italian and10.5% [n=2] American. Fifty-nine percentage [n = 11] were unilateral below-knee (BK), 26.3% [n=5] unilateral above knee (AK); 10.5% [n=2] bi-lateral BK an 5.3% [n=1] bi-lateral AK.

2.2. Pilot study

The pilot study consisted in two parts. The first part involved three volunteer participants with no disabilities. The aims were to a) test the structure and flow of the first draft structure of the experiment b) check the duration of the whole experiment and c) record the feedbacks of participants regarding the understanding of the experiment directions. The researcher made use of cards showing a 2D representation of prosthetic devices and did not make use of a voice recorder.

The second part involved four volunteer participants with no disabilities. The aims of this second investigation were to a) test the final structure of the RGT interview b) check the time duration of the experiment and c) test the correct visibility images and videos on screen. The researcher made use of a voice recorder and tested the analysis of the data.

2.3. Procedure

Before starting the interview, the researcher recorded: gender, age, nationality and length of time after amputation. The interview was recorded and consisted of two sections, where only the first section (the RGT interview) has been considered for this work. A slightly amended application of the technique has been applied for our experiment:

(1). The participant was shown a Participant Info Sheet and asked if they agree to the use of a voice recorder. The aim of the investigation, the procedure and the need for the participant to provide an objective evaluation of the devices were explained in this document.

(2). The participant was invited to select three prostheses from the set

(3). The three prostheses were discussed in the interview – the question asked by the researcher was "what do two of these elements have in common, and how do they differ from the third?"

(4). The answers was further explored by asking the question "why?" for detecting more details

(5). Points 2, 3, and 4 were repeated three times. Before starting the first round, the researcher asked the participant to include one of the two realistic-looking devices in at least one of the triads and to comment on the level of human-likeness. The purpose of these questions was to investigate the level of attraction for human likeness in prostheses.

(6). The researcher transcribed the descriptions into the repertory grid. The repertory grid is a template sheet where the preferred option is placed on the left side (e.g. colorful pigmentation), and the non-preferred issue on the right (e.g. dark pigmentation). In the middle there are five empty spaces for the participant to use to indicate their preferences in the next step.

(7). The researcher asked the participant to use the repertory grid to rate their constructs pole between 1 and 5, by considering the constructs to be associated with the aesthetic of their ideal prosthetic device

The investigator made sure that the statements of the participants were documented robustly in the grid by a) asking people to repeat and clarify the concepts whether the information where unclear, b) show the participant the grid before their marking and asking them to confirm the statements were reported appropriately.

The main differences between the original RGT and the adapted version for our investigation are:

- Where the original RGT usually display to participants elements they are already familiar with, our procedure proposes to users products they have never seen before

- The original RGT expects the participant to rate all the elements shown within the grid, where in our version we required the participant to rate in the repertory grid only their ideal prosthetic device and not all the elements (i.e. prosthetic devices) shown. This helped to keep the experiment more focused on the design aim and to keep the time of the experiment within the scheduled interview time

Ethics

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

2.4. Elements for constructs

To conduct the RGT experiment, 9 3D images of prosthetic devices (Fig. 2) and 1:1 poster format of A1 size were shown in order to achieve a standard realistic visualization of the prostheses. Eight prostheses were designed by the chief researcher and modelled by using SolidWorks 2013 x64 Edition, whereas prosthesis number 8 has been taken from an open-source database. The models 1, 2, 4, 5, 6, 7 and 9 are a set of 7 prosthetic models representing robotic devices appearance. Those models aimed to test the attraction of people for robotic features and be data source for the design elements and principles. Prosthetic 3 is a non-realistic looking devices aiming to represent a NHS cosmetic model with a low level of realism, where prosthetic 8 represents a highly realistic device. Prostheses 3 and 8 were inserted in the set to test the level of attraction and/or preference of participants for realistic devices.

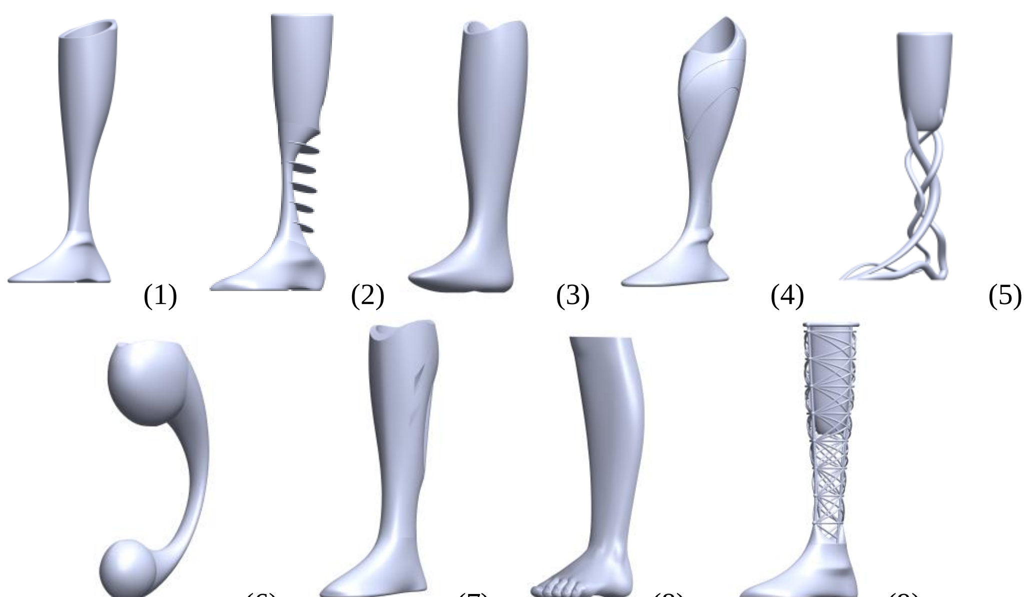

Fig. 2. The set of visual below-knee prosthetic devices designed to test the RGT as method of data collection

3. Results

The data analysis for the 19 participants provided us with a total of 135 constructs, giving a mean of 7 constructs elicited by each participant. The constructs were couples of polar statements and aimed to describe preferences and dislikes. The participants were expressing their impressions of the visual of prosthetic devices using their own words and each statement was depending on the personal interpretation of the participant for the features of the devices compared at each stage. Table 1 shows an example of how the grid with polar constructs (made of two opposite pole statements) completed by participant ‘J’.

Table 1. Example of RGT grid

Category	Preferred pole	1 to 5 preference placement					Opposite pole
1a	Non-Human likeness look	**1**	2	3	4	5	Human likeness look
1c	Colourful	**1**	2	3	4	5	Human skin colour
1C	Broken shiny metal	**1**	2	3	4	5	Human looking
3	Functional	1	**2**	3	4	5	Human looking
2	Artistic	**1**	2	3	4	5	Human looking
1b	Big Ankle	1	**2**	3	4	5	Thin ankle
1C	Continuous pattern	1	**2**	3	4	5	Web – separated pattern

According with the aim of our investigation, the constructs have been labelled under three categories 1) Aesthetic 2) Emotional and 3) Pragmatic (Table 2). Category 1 includes the majority of the constructs and grouped all the statements related to the visual appearance of the devices. The second category was elicited by almost all the participants, to include the emotional impressions that the visual prosthetic design shown was giving to participants. Category 3 includes the aspects reconnected to the functionality and comfort impressions that the prosthetic models suggested. Only the first category is considered within the analysis of this paper.

Table 2. Categories of constructs – aesthetic only is considered for our discussion

Category	Description	Sub-category	Frequency
1. Aesthetic	Visual aspects of prostheses	1A) Human or non-human likeness look	1A) Total users: 19/19 Total constructs: 23
		1B) Anatomical outline Tibia Ankle Toes Whole	1B) Total users: 13/19 Total constructs: 17 Tibia: 3 Ankle: 4 Toes: 3 Whole: 7
		1C) Design details	1C) Total users: 17/19 Total constructs: 56
2. Emotional	Non tangible observations / Feelings		Total users: 16/19 Total constructs: 25
3. Pragmatic	Issues reconnected to comfort or functionality		Total users: 11/19 Total constructs: 14

Category 1: Aesthetic constructs

The aesthetic constructs group all the issues raised by the participants involving the visual aspects of the prostheses and is the most important between the three categories, as it the only one that guides our understanding for classifying aesthetic qualities. This section counts a total of 96 constructs and is sub-divided into three groups according to the different theme: 1A, 1B and 1C.

- **1A - Human and non-human likeness**: refers to the constructs evaluating attraction for the realism of the prosthesis. For example we either had “human likeness look” as Preferred pole (P) and “non-human likeness look” as opposite pole (O), or the other way around. Category 1A is particularly relevant as the rating assigned to preference for human or non-human likeness look affect the evaluation of the other categories. Those Constructs raised by all the participants, for a total of 23 constructs all over them since some participants remarked the concept of human likeness attraction. By considering this category, we can observe data for the level of attraction for realistic or robotic devices.

The majority 63.2% [n= 12] favour attraction to robotic devices, 21.1% are attracted to both robotic and realistic and only the 15.8% of the participants stated attraction for realistic devices (Table 3).

Table 3. Levels of attraction for realistic or robotic looking devices

	Frequency	Percent
Realistic	3	15.8
Robotic	12	63.2
Robotic and realistic	4	21.1
Total	19	100

- **1B - Anatomical Outline**: the anatomical outline indicates the external form of the prosthesis related to the human anatomical proportions for the below limb leg. It includes all the parts of the prosthesis (i.e. tibia, ankle, feet, and toes). An example could be found as “big ankle” (P) and “thin ankle” (O) for i.e. an amputee attracted towards a ‘bulky’ appearance for the ankle. These constructs interested 13 participants for a total of 17 constructs. By separating aesthetics characteristics referring to human outline between the two categories 1A and 1B, that in fact may be considered part of same category, we aimed to facilitate the discussion around the attraction of users for human-likeness in a more detailed manner.
- **1C – Design Details**: refers to the details of the form of the prosthesis, and includes specific statements of the elements detected by the amputees for the devices to be compared. This point offers mainly (but not exclusively) a list of characteristics noticed within robotic looking models design characteristics. Within this group we can find statements like “colourful” (P) – “human skin colour” (O) or “continuity between leg and feet” (P) – “non-continuity between leg and feet” (O). This category encloses 56 constructs and refers to the more personal details detected by the participants when undertaking the RGT.

4. Discussion

4.1. Design Principles and Elements in Visual Prosthetic Design

Constructs from category 1A lead us to assume that the majority of prosthetic users preferred robotic design over cosmetic design. This data confirmed the fact that people were not happy of receiving the standard cosmetic model, however they were not happy neither with a basilar non-realistic option like the uncovered device as usually provided by the public health system. The people interviewed expressed preference for receiving a more visually-elaborate product.

After classifying the other data obtained during the interviews, we aimed to use the results for creating a universal system of guidelines for the aesthetic of prosthetic devices. The constructs categorised within 1B and 1C (anatomical outlines and design details) are identified as data source for defining the guidelines for design Principles and Elements in visual prosthetic design. Specifically, a classification for a set of design elements and principles has been outlined. In the following sections we describe the meaning of each component for the principles and elements.

1B collects constructs on the anatomical outline of the prostheses in relation to similarities and differences with a real human leg outline. When eliciting the constructs, 13 up to 19 participants (for a total of 17 constructs) made observations regarding the anatomical outline of the prostheses by referring to sections of the leg such as: a) Tibia, b) Ankle, c) Toes and d) whole below-knee section - examples of the constructs recorded are i.e. shape of the ankle, outline of the tibia, presence of toes, general outline of the full prosthesis etc.

The majority of the people interviewed stated preference for a device with a realistic or semi-realistic outline form (note: outline form has not to be confused with a full realistic human form – it refers only to the realistic shaping), however the preference for the different elements/patterns of the device was strictly subjective. For instance, participant J stated as preferred pole the presence of a big ankle, where at the opposite stated presence of a thin ankle, where participant C stated to as a preferred pole to have the presence of toes, and as opposite a prostheses with no toes.

When starting the interview, we observed that participants were particularly concerned on the level of human anatomy to be reproduced in the prosthesis by stating attraction for devices respecting the outline of a human leg (or only a few sections) or being attracted by outlines for devices that do not reproduce the human anatomy at all.

Design details grouped in section 1C included the largest group of constructs: 56 pairs from almost all the participants (17 people). This category collects design details referring to observations reconnected to the individual visual form of the prosthesis. The information collected here are the constructs responding to the very personal requirements of the users for their prosthesis, it lists the specifications of the design a prosthetic users would like to find in his/her ideal model.

Because of the higher number of constructs recorded within this theme and because of the aim of the experiment, we could classify this group as the most important between the three categories.

According with the nature of their origin, the constructs under category 1C have been reviewed and initially subsequently sub-divided with labels, including: Unity, Symmetry, Colour, Pattern, Geometrical forms, Organic forms, Sculptural cavities and extrusions, Symbol and natural elements and Fashion.

The classification of the constructs followed the criteria of division of the chief investigators according to their design background experience. Subsequently, the labels attributed to the set of constructs has been reviewed and validated by the contribution of three designs experts in prosthetic design, emotional design and product design. After receiving an overview on the aim of the experiment, the experts considered the classifications and labels and offered their impressions and minor revision suggestions.

After this process of correction, a defined classification for a set of design elements and principles has been outlined. By selecting and elaborating the data obtained, the factors included in the table of design principles include:

- Proportion
- Unity

Where factors included in design elements include:

- Patterns
- Geometrical components
- Organic components

Design Principles

We identify as design principles those guidelines whose ‘direct’ the design of a prosthetic product in order to give an order to the elements composing it. By referring to the concepts of ‘concinnity’ (Coates, 2003), where objective concinnity “just feels right” to the observer of any culture and any period, and is also claimed to be expressed by providing to the product “stability” and “simplicity” - we attempt to identify the principle with this concept.

The idea for principles is that the design ordering the elements and anatomy of the prostheses should be universally perceived as “just right” and balanced.

From the descriptions of participants coming from the same RGT data collection, we noticed that the strongest concern of people in relation to their emotional impact was focused on the degree of human shaping of the leg (i.e. if the human outline was respected or not), or rather the category 1B. In other words, the driving comments (less in quantity but higher in quality as people spent longer time describing them) were not mainly focused on the kind of elements chosen for the design, but more in the principles according to how they were applied to the prosthetic design. We identify the different levels of “human likeness shaping” of the leg with the term ‘level of abstraction’. The abstraction in the design has been identified as a priority for amputees and being inserted in the aesthetic design principles of prosthetic design.

Proportion

The concept of proportion has been outlined by considering the constructs grouped under categories 1B (anatomical outline) and the constructs of 1C (Design details) of ‘Sculptural Cavities/Extrusions’. The concept of proportion refers to the level of abstraction of the outline of the prosthesis in relation to a real limb outline. Outline refers to the shaping of the model. The level of abstraction can be identified under level 1 when the proportion of the sections of the leg (i.e. tibia, ankle and toes) respect closely the external proportion of a real limb and little or no presence of cavities and extrusions is designed in the device. Under level 2 we classify devices that reproduce somehow the general outline of a leg, but where some sections clearly do not respect the human proportions. Presence of cavities and extrusions are more remarked (i.e. extruded sections in the heel). Within level 3 we found the more “extreme” level of abstraction, where the human outline is altered at the point of finding little or no resemblance with a natural limb, the sections of the prostheses can show pronounced cavities/recessions and extrusions. We believe that compared to Unity and Placement, proportion is the characteristic that covers more weight in affecting the abstraction level perception of the observer.

Unity

Unity refers to the presence (or lack) of continuity between the designs sections and or the design patterns, and has been detected as one of the constructs more repeated within the list of design details (1C). Design sections include tibia, ankle and foot, where the patterns are the aesthetic elements applied on the device. At level 1 we have a design perceived as more organic and connected between each part, at level 2 a design with a semi organic appearance, where at level 3 we find a design perceived as non-organic and disconnected. The level of abstraction showing a homogeneous design can be identified under level 1 where design unity between the tibia, ankle and foot and/or continuity in the pattern of the prosthesis (i.e. one pattern only) is respected. Under level 2 we have a medium perception of continuity, with partial unity between the tibia, ankle and foot - or discontinuity between the patterns of the prosthesis (i.e. more than one pattern used along the prosthesis). Within level 3 it can be found a design with a remarked discontinuity between the parts and an optional non-unity within the patterns can be found.

Since the three criterions points are subject to individual perceptions, prostheses 1, 2, 5, 9 can be classified in the category that we found more appropriate, but might be perceived by other subject in the adjacent one. Specifically, 2 and 9 are classified, based on our guidelines, under area 1; prosthesis 1 under area 2, and prosthesis 5 under area 3. However, 2 and 9 could be classified by other users/designer under area 2; prosthesis 1 could be (unlikely) be classified under area 1 and prosthesis 5 under area 2.

Table 4. Design principles for visual prosthetic design

		Level of abstraction 1	Level of abstraction 2	Level of abstraction 3
A. Proportion		**Human anatomy outline respected**	**Deformation of human anatomy on some sections of the prosthesis**	**Human anatomy outline non respected**
Anatomical outline (1B) + Sculptural cavities and extrusions (1C)	Number of constructs: 17 Including: Tibia Ankle Toes Whole	The outline of the leg follows almost perfectly the outline of a real leg or of a cosmetic device Anatiomical propotion is met	The outline of the leg reminds the outline of a real leg, proportion of some sections are clearly altered Anatiomical propotion is partially met	The outline of the prosthesis is fully altered Anatiomical propotion is partially or not met al all
B. Unity		**Continuity**	**Medium level of continuity**	**Contrast**
(within design sections) (1C)	Number of constructs: 8	Involves design unity between the tibia, ankle and foot or continuity between the pattern of the prosthesis (i.e. one pattern only). Visual impression of an organic design	Partial design unity between the tibia, ankle and foot or discontinuity between the patterns of the prosthesis (i.e. more than one pattern used along the prosthesis). Semi-organic design	No unity between the tibia, ankle and foot, and/or discontinuity between the patterns of the prosthesis (i.e. more than one pattern used along the prosthesis). Idea of discontinuity in the design of the prosthesis.

Design elements

The design element/s in the prosthetic device responds to a very subjective taste from the observer. We connect the idea of elements to subjective concinnity (Coates, 2003). Subjective concinnity represents the novelty of a design: values, beliefs, individual taste and stands on the subjective taste of the observers. Because of the peculiarity of these constructs, and because of the high number of them, the classification into categories has not been straightforward to identify.

The source of the list of design elements comes from a selection of aspects detected in category 1C (Design Details). After the first labelling validated with the support of three experts, the researchers selected most of the items to be classified in three sub-categories including the ones presented in the chapter design details. The process of division implied a few steps:

- After listing in one whole table all the constructs of 1C, a first set of suitable labels has been identified. The this first set of labels included unity, symmetry, colors, patterns, geometrical forms, sculptural cavities and extrusions, symbols/natural elements and fashion
- Labelling of the constructs present in category 1C have been subsequently revised. The revision included a) moving the label of unity to the design principles and uniting cavities and extrusions within the concept of proportions for principles and b) eliminating labels with limited number of frequencies (i.e. symmetry =1)
- When the final set of constructs was identified, the elements colors, patterns symbols and fashion where sub-grouped within the label of "patterns".

The results of a sub-classification of all the issues found within 1C are illustrated in Table 5.

Table 5. Design elements for visual prosthetic design [detected from Design Details (1C)]

Elements	Frequency	Specifications (f=frequency)
Patterns	18	Colors (f=9) Pattern (f=6) Symbols/natural elements (f=2) Fashion (f=1)
Geometrical components	13	Geometrical forms
Organic components	8	Organic forms

Patterns

'Patterns' is defined as "any regularly repeated arrangement, especially a design made from repeated lines, shapes, or colours on a surface refers to the covering decorations that can be"[1] . A similar understanding of the concept is made within our context, where the decorations over a prosthetic form are identified within this category. Within this category we also grouped items originally labelled under the categories Colours, Symbols and Fashion. Examples of patterns listed by the interviewed were "Scottish Flag decoration (P) – no decoration (O)" (i.e. pattern), "colourful (P) – human skin colour (O)" (i.e. colour), "presence of Celtic knots" (P) – "plain" (o) (i.e. symbols), and "hill foot" (P) – "flat foot" (O) (i.e. fashion).

The investigators decided to group these four categories within a singular category, as we believed that the all of them were united by the same design family. With a frequency of repetition of 18 constructs, pattern is the most relevant element when compared to Geometrical components and Organic components.

Geometrical components

Geometrical components are identified for all the elements of C1 described as "geometrical forms"- and have been identified within 13 elicitations. Examples of those constructs are "triangle shaping (P)" – "surface without slots (O)" or "Rod details (P) – Elements interfering with anatomical shape (O).

Organic Components

Organic components identifies both constructs that have been labelled with the direct constructs involving the word "organic" (i.e. "Organic Shape" (P) – "Perfectly straight" (O))" and the elements that have been labelled by the investigator under this category even if the word organic was not used (i.e. "linear/smoot" (P) and "extravagant/not human" (O)). Organic constructs registered were only 8.

4.2. Visual Prosthetic Design Process

The design approach that has been elaborated for visual prosthetic design is here proposed. The idea is that, in order to obtain a design which could respond the closest possible to the expectation of the wearer, a user centred design approach has to be applied. The main aim is to transliterate a set of visual expectations of the amputees for their prosthesis from a non-tangible idea to a quantifiable set of characteristics to be then reproduced in the form of their robotic looking prosthetic device. In order to apply this method, we identified the professional figure of the Visual Prosthetic Designer. The essential role is to follow a user centred prosthetic design process from the data collection to the design concept.

[1] http://dictionary.cambridge.org/

The specifications of the design system applied by the visual prosthetic designer have been detailed explored in our previous work (Stefania Sansoni, Wodehouse, McFadyen, & Buis, 2015).

The first step in the design process is the application of the RGT in a one-to-one interview between the designer and the user. The RGT prosthetic models are prostheses chosen by the designer to be displayed as 3D images/videos or real models. When completing the data collection and obtaining a grid of constructs referred to the ideal device of the interviewed, the second phase of the process can start. The designer should be able to label the results under the design principles and elements (Table 6 offers an overview of them) in order to have a quantifiable data set of factors to be used for the final design. An example is proposed to clarify the process.

Table 6. Design Principles and Elements for Aesthetic of PD related to level of artificiality in the device

Design principles	Design elements
Proportion (level of abstraction 1, 2 or 3)	Pattern (color, texture, symbols, fashion)
Unity (level of abstraction 1, 2 or 3)	Geometrical components
	Organic components

When accounting the numerical data (between 1 and 5) recorded in the grid, the constructs can be transformed in factors translated in the grid evaluation. By including an example, we can list a set of constructs as example:

- (P) Realistic outline of the upper section – (O) unrealistic outline
- (P) Very thin ankle – (O) bulk ankle
- (P) Organic connected design – (O) two separated sections
- (P) Application of decorations all over the device – (O) no pattern
- (P) Bright red – (O) skin colour
- (P) Presence of knot decoration – (O) no pattern
- (P) Triangle-shaped components – (O) no components

After collecting the constructs, the visual prosthetic designer will transcribe the constructs within the RGT grid. A first stage of 'data cleaning' will be performed by i.e. eliminating constructs that have been repeated twice or constructs that are not relevant with prosthetic design. After the grid will be completed, the designer will provide to the user the grid by asking them to mark the weight of each construct for their ideal prostheses between 1 and 5, according to the weight that each statement represented (**Error! Reference source not found.**a) During this process the designer will have the chance to make the user reflect about the role of each feature applied to their own device, and gives them the possibility to quantify properly the weight of each future applied for the device.

After the collection all the constructs, elements and principles should be divided. When detecting the elements, the process would be to label the constructs obtained under the three categories Patterns (A), Geometrical (B) and Organic (C) components. The expectation would be to collect a higher number of specifications for Category A and a minor set of observations for either B or C. The requirements of users for the elements are very personal and the needs would be subjective from person to person.

The designer will then label the principles of proportion and unity according to the levels of abstraction, and then identify and classify the elements. Principles: A2, B1 to be considered for the framework process and elements: A (colours), A (symbols), B (triangles) for the specifications of the design. The specifications of the labelled constructs are shown in Table 7.

Table 7. Example - Labelling of the specifications for Design P&E

Design principles	Design elements
Proportion: level of abstraction 2 Deformation of human anatomy on some sections of the prosthesis	Patterns: color, symbols
	Geometrical components: Yes
Unity: level of abstraction 1	
	Organic components: N/A

Our experiment as outlined in the method of this article ends at this stage. We detected a procedure for design elements and principles and simply labelled all the data obtained. However, the complete design process applied by the visual prosthetic designer continues and will be outlined here as following.

After collecting the specifications for the design, the designer can start to outline a more detailed idea of the required design. The designer can follow the most suitable strategy according to the design specifications. Our methodology then advises the designer to propose to the user a second stage of design evaluation, in this case to be referred to the proposed model. The idea is to display to the user the prosthetic design proposal to be ranked under a second RGT evaluation grid for the re-elaboration of the constructs proposed in the first session. This second grid re-proposes the ranking of each constructs elicited with the numerical evaluation attributed – Fig. 3b offers an example.

The user would then be asked to evaluate if the issues listed in the first session have been designed in a way to correspond the requirements. If any factor would had been addressed in the undesired level, the user should rate the perception of the draft design in order to quantify under which extend a characteristics should be amended. This stage could be implemented by set of more open ended questions where the designer will detect more specifications on the details required by the user, and where a dialogue on i.e. material availability, length of production and cost can be take place. The aim is to provide the user a more realistic idea on the final output of the design process by accounting also other variables.

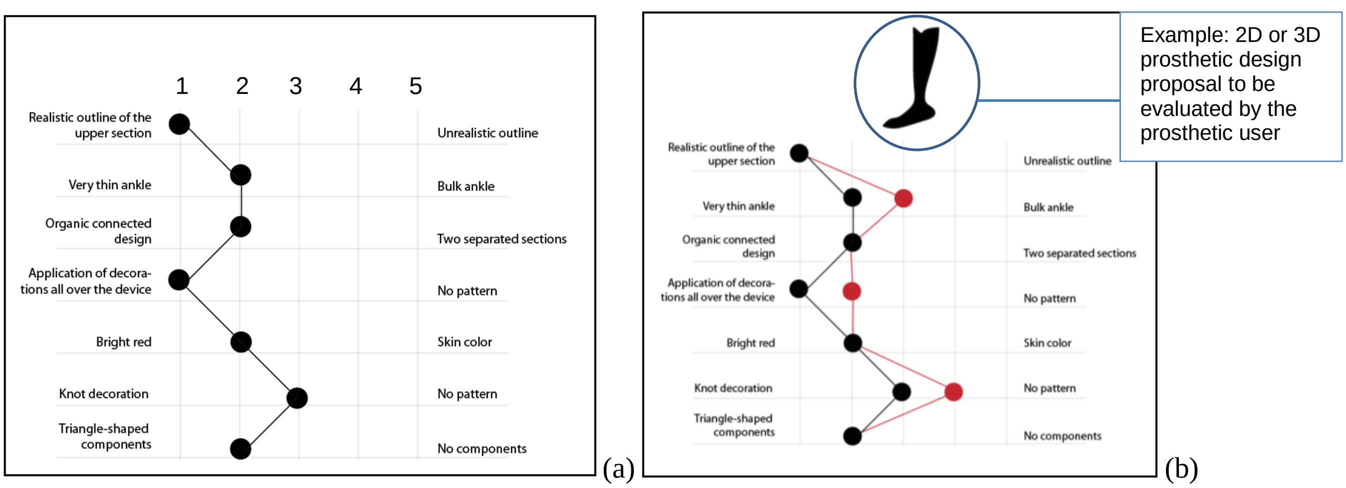

Fig. 3. Example of RGT application stating the level of preference for the constructs on a scale of 1 – 5 (a) and evaluation of the RGT in relation to the design proposed by the designer - where the constructs are not represented in the desired way, the user can amend the weight of the factor (correction represented in red) (b)

Limitations of the investigation

One limitation of the investigation is that only the RGT interview and data collection has been tested (i.e. phase 1 and 2), where the specification of the practical design preparation have not. Testing the full design process would be a desirable future aim for the field of visual prosthetic design. Our research approach during the whole investigation did not include a full manufacturing design plan, therefore a specific approach including information for i.e. cost, material, manufacturing details is not aimed to be provided for this work but would be addressed in future works.

5. Conclusion

This work presents the RGT for the design of visual prosthetic devices. This chapter presents and innovative and very first approach for data collection with prosthetic users - where the procedure is tested through interviews with 19 amputees. The elements used for the data collection are a set of 9 prosthetic devices representing variegated visual features and different levels of realism. The results of the RGT were a large set of constructs (135) classified within three categories (aesthetic, emotional and pragmatic): the category 'aesthetic' included a set of sub-specification that were used for designing our final classification of design principles and elements. Principles are those guidelines whose 'direct' the design of a prosthetic product in order to give an order to the elements composing it and included *proportion* and *unity* to be potentially applied within three levels of abstraction. Elements are the parts of the design that provide it with 'novelty' and included *patterns*, *geometrical components* and *organic components*. Principles and elements are identified in our study as a key factor for transforming the emotional needs of prosthetic users from non-tangible qualities to measurable aesthetic features. These design guidelines should support the visual prosthetic designer both to address the data collection with the prosthetic users by extracting and quantifying aesthetic needs and to address the design of robotic models.

Our hope is that these initial findings have established a more coherent overview of the challenges of visual prosthetic design, and that the proposed methodology provides a basis for other researches and practitioners to define a more focused procedure for this aspect of prosthetic design.

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S. Sansoni is a PhD student in the Department of Design, Manufacture and Engineering Management at University of Strathclyde investigating the field of visual prosthetic design. 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 aims to improve the emotional attachment of amputees to prosthetic devices and enhance their body vision and encompasses product design, psychology, emotional design and prosthetics.

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A. 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.

A. 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.