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AN EYE-TRACKING SUPPORTED INVESTIGATION INTO THE ROLE OF FORMS OF REPRESENTATION ON DESIGN EVALUATIONS AND AFFORDANCES OF ORIGINAL PRODUCT FEATURES

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Abstract

The paper investigates the relationship between the forms through which products are represented and the outcomes of evaluations made by observers. In particular, the study focuses on perceived affordances of creative designs, meant as the capability of capturing original elements and corresponding functions, for products presented through static images or videos. Also thanks to the use of Eye Tracking, the experimental results show how dynamic effects that involve salient aspects of products, as well as creative features, are critical to observers' capability of capturing design intentions.

Keywords: design creativity, product design, design evaluation, design affordance, forms of representation

1. Introduction

Especially when creativity is involved, mismatches can arise between designers' intentions and users' or consumers' perception of designed products (Khalaj and Pedgley, 2014), which represents an undesired outcome (Crilly et al., 2004). In order to identify potential misalignments or unwanted perception outcomes, designs benefit from being evaluated by external observers; markedly, feedback is crucial in responsive design methods (Bacciotti et al., 2016). In the present paper, the authors use the term "evaluation" as any feedback provided or reactions had by observers that interact with or experience what is designed, either the product itself, the representation thereof, or any of its depictions in intermediate design stages. Evaluations are valuable especially if designs exhibit remarkably unusual features or structural elements. Those are indeed featured by the chance to conflict with habits (Becattini et al., 2017) and give rise to bewilderment. In this context, the importance of designs' evaluation is stressed by Arrighi et al. (2015), who hypothesize that it is possible to improve designs and save resources with an earlier involvement of the user in the design process.

The study of affordances is diffused among those that require design evaluators. The concept of affordances in design was particularly popularized by Norman (1999) and Maier and Fadel (2009), which was followed by considerable debate especially on a theoretical level (Masoudi et al., 2019) — a thorough review of the topic is out of the scope of the present paper. In general, a strict vision on the affordance concept links it to the actions carried out by users on a product or system in order for it to perform certain functions. A wider meaning is attributed to affordances to make them include understanding of specific product characteristics and consequently offered advantages and delivered

benefits beyond actions and functions, e.g. (Cormier and Lewis, 2015). The verification of this understanding can be considered of paramount importance to verify the presence of the above mismatches when it comes to evaluating creative products.
As the next section better documents, any kind of evaluation might be affected by the way designs are presented. The term "forms of representation" is used thereinafter to indicate different illustration fashions and interaction media intended to depict and allow interaction with designs. The present paper is concerned with investigating the role of forms of representation on evaluations of creative products and specifically on affordances. More in details, different visual forms of representation will be considered here, as the first interaction with designs routinely happens through sight and that might be a primary driver of evaluations (Khalaj and Pedgley, 2014).

2. Background and objectives

2.1. Forms of representation used to make design evaluations

Designers can benefit from the users' evaluation along different stages of product development, which are featured by an increasing level of detail as design progresses. Especially in early and intermediate design stages, the evaluation is thus carried out on products' representations rather than on the final product. Forms of representation such as sketches, 3D models, renderings, virtual and physical prototypes are consequently involved during the design process and used by designers to overview the progress of their project ideas (Edelman et al., 2009). It is of anecdotal evidence that the different forms of representation entail different degrees and modalities of interaction between the designs and the evaluators.
Some scholars have presented multiple forms of representation to perform distinct evaluations in the same work. For instance, in (Samantak and Mi, 2017), users' experience and satisfaction have been investigated through five different representation forms. The main aim was to get different feedback in every design stage based on the level of detail of the corresponding form of representation. Christoforakos and Diefenbach (2019) compared two low-fidelity representation forms in order to obtain a better users' evaluation in the early design stages, by involving as few resources as possible. Diefenbach et al. (2010) considered the advantages of early product concept evaluation of user experience, satisfaction and cognitive perception. Here, users have been exposed to forms of representation with an increasing level of tangibility. Conversely, other scholars investigated experience made with physical prototypes and virtual ones involving tools such as virtual reality (VR). For example, Mengoni et al. (2009) compared virtual prototypes to VR experience with the same product in order to investigate users' emotions and product attractiveness. Yoon (2006) conducted an experimental case study involving furniture design to deepen the relation between user experience and VR interfaces. As aforementioned, all these scholars used different forms of representation to make multiple and distinct evaluations. Just few investigations have involved the same kind of evaluation while using different forms of representation (Dong and Liu, 2018; Lo et al., 2013).

2.2. Literature gap and importance to address it

Although multiple forms of representation are present in a few abovementioned contributions, none was intended, to the authors' best knowledge, to investigate systematically which ones are the most suitable for a specific evaluation aspect. This represents a literature gap in the authors' view also based on the observations that follow.

- Visual aspects play a role in people's behaviour and products' acceptance, as stressed particularly by Haug (2016).
- A consumer's purchase decision is affected by the psychological response induced by a product's aesthetics (Chen and Chang, 2016), which may give rise to different perceptions according to the way a product is observed and experienced.
- Representations with different levels of accuracy and sophistication give rise to different exploration strategies, as revealed by Reid et al. (2013) by means of Eye-Tracking (ET) – this affects opinions on products and purchasing decisions.

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- The different forms of representation of a product considerably affect the conveyance of symbolic design aspects that might play a crucial differentiation role (Artacho-Ramirez et al., 2008).
- Preliminary tests that aim to understand what triggers surprise when observers are exposed to surprising products reveal the predominant role of the structural dimension, but this should be biased by the form of presentation used during the experimental campaign (Becattini et al., 2016).

2.3. Overall scope of the research and paper's objectives

The large extent of the literature gap shows that a vast number of studies should be conducted to understand how forms of design representation affect evaluations fully. As the topic has been barely addressed in the design literature, the first studies of this kind are necessarily explorative and the present one is of no exception. Likewise, any combination between multiple forms of representation and design evaluations would contribute to the scope.

The authors have indicated in the Introduction section that the evaluation of affordances might well represent a primary objective within creative design; as such, the understanding of product functions is the kind of evaluations considered in the present paper. The choice of leveraged forms of representation follows based on the recalled predominant importance of visual interactions in design and the explanation that follows. Overall, as affordances are connected to actions, they might be better perceived through dynamic effects. More explicitly, according to Creusen (2011), pictures are viable to lead to misunderstanding of design characteristics, which results in misinterpretation of functionalities. Conversely, it is assumed that videos might help observers to understand design affordances.

Therefore, the specific objective of this paper is to explore how pictures and videos depicting creative products affect evaluators' understanding of their functions and peculiarities. The observation of static (pictures) and dynamic stimuli (videos) is here insightfully studied by means of the remote ET technology. ET is routinely used in design research to identify stimuli's features or regions that capture major observers' attention. ET is employed here to individuate changes in overall evaluators' visual attention when videos replace pictures as forms of representation and vice versa. Stimuli's areas that are overall mostly observed can be put into relation with the investigated understanding of creative products, so to present a wider spectrum of information concerning interactions and design affordances shaped by videos and pictures.

An experiment is presented in Section 3 aimed to address the research objectives.

3. Description of the experiment

3.1. Participants

A sample of 18 participants (9 females and 9 males) has been involved in this study. They were recruited during the initiative "The Long Night of Research" held on September 27th, 2019 in Bolzano, Italy. The participation in the experiment was volunteer and it was supposedly motivated by people's curiosity in the functioning of ET. The context in which participants were recruited, i.e. an event meant to attract citizens and show scientific works to non-specialists, led to collect a sample of participants that can be deemed extracted from a random population. Participants' demographic data were not needed for the scopes of the experiment and no written consent was required accordingly.

3.2. Materials used in the experiment and test procedure

Six different creative products, in which all the authors had identified original characteristics, have been selected for the evaluation. The number of products leveraged for the experiment was limited because of the time plausibly available by the participants. Said products can be used or benefitted from in every day's life circumstances and do not refer to artefacts normally known by field specialists. In Figure 1, the products' pictures are shown along with a brief description of their original characteristics. All the products are shown in their use context.

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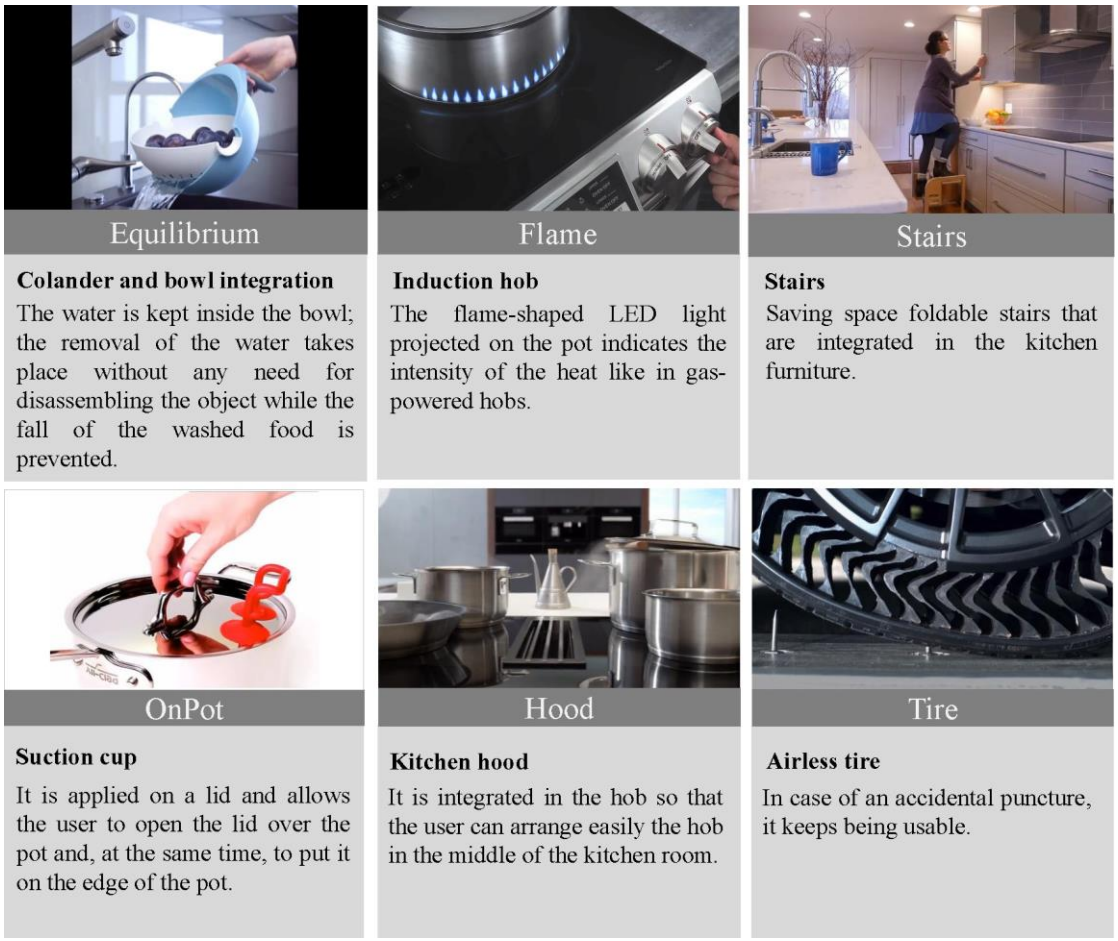

Figure 1. Pictures and descriptions of the leveraged creative products

The products were selected based on the availability of videos that illustrate these products' use. The videos were first cut in order to obtain eight-second-long clips and edited to remove text messages. The leveraged pictures coincide with the first frame of the corresponding video. From those pictures, it is possible to notice the original characteristics of the represented product and that their functions and benefits can be inferred.

Two different sequences of pictures and videos (see Figure 2) were arranged to be shown to participants on a monitor, on which a remote ET device was mounted (Tobii X2-60). The two sequences were administered to the same number of participants (thus 9 each). Both sequences included three pictures and three videos, which were alternated, and covered the whole range of the six creative designs (Figure 1). As a result, if a specific design was depicted as picture in the first sequence, the corresponding video was shown in the second sequence and vice versa. All the pictures were shown for eight seconds, so that the exposition duration of videos and pictures was consistent. Videos were displayed without any audio.

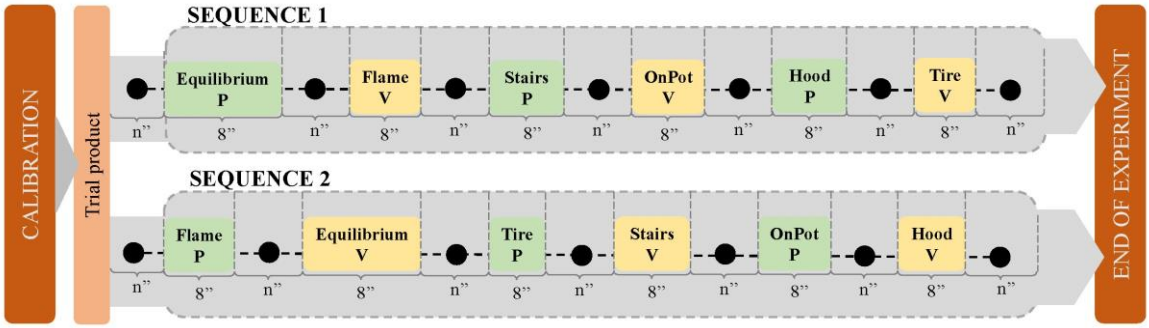

Figure 2. Sequences of displayed pictures and videos

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Before every session could start, the calibration of the ET device was performed. Each sequence included the picture of a trial product shown at the beginning to check participants' understanding of the procedure and give them final clarifications. A black screen appeared after every video and image to allow the participants to perform the required task (Section 3.3), for which unlimited time was assigned.

3.3. Task and instructions

Before the start of each session, the authors read to each participant the following test instructions. "You will see pictures or watch videos showing products for a few seconds. We ask you to observe them in silence. At the end of each display, the screen will turn black. As soon as the screen turns black, describe the product, its advantages/disadvantages and the characteristics that make it unusual. At the end of your explanation, nod, look at the centre of the screen and we will move forward. So, to summarize, you have to describe the product, its advantages/disadvantages and the characteristics that make it unusual." In this way, the authors were able to monitor products' affordances in terms of function, perceived advantages or disadvantages, and/or elements that make their designs unusual. Beyond adopting the wider meaning of affordances, the authors asked for benefits and shortcomings to urge participants to provide articulated descriptions that could better reveal if comprehension had taken place, as well as if the presence of unusual features had led to any misalignments with designers' intentions. As the experiment was run in Italian, English or German based on preferences of each participant, the above text instructions of the task were available in all the three languages to minimize language bias.
Each participant agreed to be audio recorded. Therefore, the authors could collect the audio content of participants' reply to the task and could use it for subsequent analyses.

4. Analysis of data and results

In order to investigate the effects of different forms of representation (pictures and videos) in creative designs' affordances, different analyses were performed. The recorded audio files were exploited for evaluating the participants' perception and understanding of designs. The participants' visual attention acquired through the remote ET was analysed; differences were investigated based on products' understanding and forms of representation.

4.1. Differences in affordances based on forms of representation

The authors established that the understanding had taken place when the participant had mentioned the original characteristics of the product, connected benefits and/or disadvantages thereof, in line with the descriptions provided in Figure 1. Table 1 indicates examples of actual answers through which it is possible to state that the understanding had taken place. The understanding was considered insufficient when a participant's description was limited to the individuation of the main function of the products without any mention to their original characteristics. The results are illustrated in Table 1, which shows the number of participants who recognized the original characteristics through pictures and videos.
Table 1 reveals a substantial unbalance in terms of understanding between products provided with pictures (23 in total) and videos (49).
Based on results, the perception of affordances, functions and benefits, consistent with designers' intentions, is boosted by the presence of dynamic elements, which supports the initial suppositions.
From these outcomes, it is also possible to make the following remarks.

- Four products out of six were understood by all the participants provided with the corresponding video. Here, it is plausible to assess that what was shown in videos requires no further interpretation from the observer's side.
- The products Flame and Tire are those with the lowest score in the understanding when videos are leveraged. While the former still presents improvements with respect to the display of pictures, the video has played no particular benefit for the latter. It is plausible that this missing contribution of a dynamic stimulus when it comes to Tire might be particularly affected by the participants randomly chosen. It is also worth noticing that this specific product is the one featured by major technical advancements within the set of selected

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designs, the only one users do not directly interact with, as well as the only one that is not used in an indoor environment.

- Stairs and OnPot show the greatest gap in the understanding between the use of pictures and videos. With reference to the latter, no one was able to explain functions and benefits of the object through the corresponding picture. Here, the level of understanding could have been affected by the first frame of the video, i.e. what was used for the static stimulus, as this did not show the creative product in its functioning position.

Table 1. Number of participants who have (not) understood the original characteristics and/or related benefits/disadvantages of creative product features

Products	Pictures understood (Not understood)	Videos understood (Not understood)	Understanding example
Equilibrium	7(2)	9(0)	It is convenient to wash and drain fruits with a single tool
Flame	2(7)	7(2)	The flame is projected so you can understand the heat intensity
Stairs	2(7)	9(0)	You waste less space putting the ladders into the furniture
OnPot	0(9)	9(0)	You can place the open lid on the edge of the pot
Hood	5(4)	9(0)	Useful when you have the kitchen in the centre of the room
Tire	7(2)	6(3)	The advantage is that it doesn't stall with punctures
TOT.	23 (31)	49(5)	

4.2. Overall visual attention on videos and pictures

In the present subsection, the visual behaviour is analysed irrespective of the understanding of products. A general analysis of ET data was performed by comparing the heat maps for pictures and videos extracted through the software Tobii Pro Studio. Heat maps are diffusedly used in design research and markedly in product evaluation to establish qualitatively what has attracted attention in stimuli and how this has affected design or evaluation tasks; examples are (Ishak et al., 2015; Nagai et al., 2017).

The heat maps (such as those depicted in Figure 3) indicate the cumulated absolute duration (for nine participants each) of the fixations (a proxy of attention in ET studies) on the different areas of the stimuli. Here, the considered durations of the stimuli exposition are the same for pictures and videos. In particular, for each considered product, such a duration corresponds to the duration of the video scene in which the main elements of the product and the systems that interact with it are approximately in the same relative position. Indeed, readers can notice that the upper and lower heat maps in Figure 3 refer to marginally different images, i.e. the upper ones refer to the end frames of the considered video scenes. The red spots in Figure 3 feature areas participants, on average, paid attention to for at least one quarter of the considered duration of the time exposition (approximately two seconds).

Through the illustrative heat-maps depicted in Figure 3, it is possible to notice that participants focused mainly on the products and the relevant systems useful for their understanding when exposed to videos, as opposed to pictures. More specifically, when interacting with the Equilibrium video, participants' gaze was directed to the visible effect of the product (to wash and drain food simultaneously), while the gazed area is wider in the picture. In Flame video, it is noteworthy that participants focused mainly on the control (the knob) and its effect (the variation of the flame-shaped light projection), while attention was also paid to other symbols and irrelevant hood controls in the picture.

It is plausible to conclude that the dynamic nature of the video directs observers' attentions to those specific characteristics that can be useful for the understanding of the product, especially if those are featured by some dynamic effects, e.g. the rotation of the colander with respect to the bowl, the movement of the knob.

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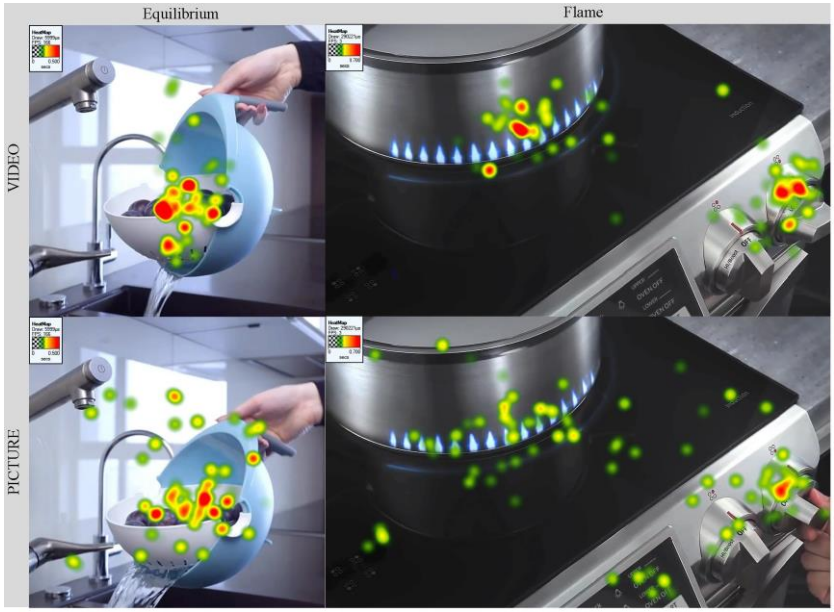

Figure 3. Heat-map illustrative comparison between pictures and corresponding videos (all the participants)

4.3. Visual foci on pictures resulting in different understanding outcomes

A more in-depth qualitative analysis was meant to compare heat-maps extracted by the observation of pictures by separating participants whose understanding was correct or incorrect (Figure 4). The Hood is here take as an illustrative example since the subdivision between participants was the most even (four participants out of nine did not understand the product's original characteristics or their role). The participants who understood the product looked mostly at the steam coming out of the pot. This probably led them to identify the reason for the unusual direction of the steam and, consequently, to understand the innovative feature of Hood.

Figure 4. Heat-map comparison between participants exposed to the picture of Hood based on their different levels of understanding of the product's creative characteristics

In general, when the observers focus more on the relevant elements of a picture, they have more possibilities to understand the products' functions and main characteristics. This behaviour is accelerated in videos as already discussed in 3.2.

4.4. Visual foci on videos resulting in different understanding outcomes

A comparison of heat-maps extracted from videos made sense for a few products, as four products out of six have been understood by all participants when videos were administered. The only product for which a comparison can be made in this context is Tire, but no particular insight has emerged through the comparison of heat-maps.

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5. Discussions and limitations

Overall, the results suggest that designers can benefit from dynamic representations when these are able to make an observer focus on creative and salient features. Of course, an obstacle might be faced when the original characteristics of a design are not meant to entail dynamic behaviours. In addition, while the present study has shown fully developed commercial products, the same kind of videos cannot be easily produced in intermediate design phases and certainly not before prototyping. To this respect, the differences are worth being investigated between dynamic and static representations leveraged during the design process, e.g. movement simulations and static depictions of CAD models, especially in terms of avoiding misunderstanding of expected functions.

The outcomes of the study are inherently affected by some limitations or experimental conditions that are worth highlighting and that are conducive to future work.

- The number of participants (sample of convenience) and investigated products is limited and allows the authors to infer partial and qualitative conclusions to be verified in the future. Given these restrictions and in line with the explorative nature of the paper, research hypotheses have not been formulated, but they might be put forward in the future based on preliminary results.
- The sample of products was selected based on convenience, i.e. availability of videos presenting the corresponding products that could be easily edited. Their representations are not consistently featured by the presence of akin elements, e.g. the user or their hand, which makes comparisons difficult. As well, the products were chosen based on their limited technical sophistication in light of the nature of the initiative meant to recruit participants. However, as mentioned in the previous section, a change of context into a more technical field when it comes to the product Tire has jeopardized the advantages generally provided by videos. While it can be hypothesized that the change of forms of representation is more impacting in product or industrial design than in engineering design, the present study is not capable of clarifying this issue. Future work might entail the repetition of similar experiments in which the (technical) complexity of products is considered and leveraged as a variable.
- The choice was made of using the first frame of videos for extracting the static stimulus, which eliminates a selection bias for pictures and favours the comparison of heat maps extracted through ET systems. Actually, different frames could have resulted more explanatory in terms of communicating the intended function of the creative design, but it would have been arguable to decide which depiction could have maximized understanding. In any case, a different selection of pictures could have affected the degree of difference in terms of perceived affordance between pictures and videos.
- The duration of videos was set to eight seconds based on the material available and this duration of exposition was replicated for pictures. As participants were not allowed to interrupt the exposition of videos and pictures before the screen turned black, it was not possible to monitor the time needed to understand the functions of the products, nor to measure when the stimuli were no longer able to provide useful information for the scopes of perceived affordances. On the one hand, the study was primarily meant to verify whether the different forms of representation affect evaluations and, to this respect, the monitoring of time was not considered a fundamental aspect. On the other hand, the presence of particularly critical elements whose observation enables the understanding of the function of creative design could have benefitted from the participants' decision to interrupt the exposition of stimuli. The use of other tools that monitor people's cognition to be juxtaposed to ET, such as neurophysiological devices, would have helped to pursue the same goal, but this chance was ruled out because of the circumstances in which the experiment has taken place.
- Although ET hardware and software allows researchers to study the visual behaviour for both static and dynamic stimuli, it is not possible to combine heat-map outputs of pictures and videos. For instance, when it comes to products such as Flame or Tire, which exhibit a more limited unbalance between videos and pictures (Table 1), it could have been interesting to compare the fixation areas of participants based on their understanding and irrespective of the form of representation. Such a comparison is made possible by the quantitative study of fixations

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or gaze durations in specific areas of interests, which can be made variable when videos are used as stimuli. The definition of appropriate and relevant areas of interest is likewise enabled by the presented results.

6. Conclusions, outlook and future work

The paper represents a first effort to study the effect of forms of representation on the outcomes of design evaluations and observations. It focuses on the affordances of creative products and particularly on the potential misalignments that creative features can engender in terms of functionalities. Indeed, unlike many affordance-based design studies, the present contribution does not take into account the range of actions or operations that a (commonplace) product can allow, as it restricts its attention on the effects of and rationale behind creative features. As for the main objective of the research, the impact of the chosen forms of representations on affordances is confirmed, as participants overall performed considerably better in terms of individuating the original functions of the presented designs when videos were employed as stimuli.

As for affordances, the ET analysis remarks that some elements are plausibly salient for the understanding of products' functioning and functions. These include the product itself, the original features thereof, the objects undergoing functions, and the acts of humans that use the products. These critical elements were particularly stressed in the selected videos through dynamic effects and this circumstance can be deemed crucial for videos' better capability of explaining intended functions of creative designs. With regard to design practice, these outcomes urge designers to put attention on showcasing the elements listed above to prevent users' mismatches with design intentions. This applies particularly when new and creative designs are displayed by pictures, which is a very frequent case.

The findings also lead to question whether dynamic effects that do not directly concern the creative features of a design might be supportive as well in terms of aligning perceived affordances with designers' intentions. To have a better comprehension of the phenomenon, future studies can address the impact of misleading or attention-diverting dynamic effects on people's understanding of (creative) designs.

Authors' future work is primarily oriented to extend the sample of participants and the set of analysed products. The latter is of paramount importance given the asymmetric differences between videos' and pictures' support to product understanding across the set of leveraged products. Other measures are planned to overcome the limitations illustrated in Section 5. In addition, the audio data can be used to infer people's predisposition to describe products in terms of important design-related ontologies or frameworks, such as the Function-Behaviour-Structure — clearly, the formulation of the task might affect those descriptions.

The authors are available to share the materials of the study to allow the repeatability of the experiment.

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