ON THE RELATIONSHIP BETWEEN AFFORDANCE AND EXPECTED PERFORMANCE

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Abstract

The paper describes an attempt to understand if and how product affordances and guessed performance alter the user ability to assess real performances during actual interaction with the product. The research work tries to experimentally find evidences of the existence of the “expectations about performance” guessed when the users see the product, if they correlate with product affordances and how the following interaction with the product modifies the users' opinion. The experiment has been performed by using four common flashlights as products and more than one hundred students as a users sample. The results of the performed test demonstrated that expectations about performance and affordances are concepts deeply intertwined.

Keywords: Human behaviour in design, Design theory, Affordance, Cognitive bias, Case study

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1 DO USERS HAVE EXPECTATIONS ON THE PERFORMANCE OF PRODUCTS (WITHOUT ANY PRIOR EXPERIENCE)?

The notion that people have expectations on the performance of products is well accepted in marketing theory and is at the core of the huge literature on customer satisfaction. After some experience, people develop fairly accurate expectations of the performance of goods and services and evaluate them accordingly. If they do not have direct experience with goods and services, they develop expectations based on analogies with close categories of products with which they have had direct experience.

The engineering design literature, however, has since long time insisted on a different concept, i.e. on the notion that people have expectations from products, *even if they do not have any experience whatsoever*, and cannot make analogical inferences based on close product categories because such categories do not yet exist. People derive inference on possible uses of products, and hence on their potential performance based on the observation of their physical features, that is, based on their design. It is the physical constitution of the product, and not the prior knowledge of it, that generates expectations in the mind of users. This notion is known in perceptual psychology, and is called *affordance*. Maier and Fadel [2008] define affordance as the set of interactions between the product and the user in which properties of the artifact are, or may be, perceived by the user as potential uses.

While this notion has gained prominence in the engineering design literature, as we will see in the survey below, little is known about the interaction between the expectations that a user may generate on the potential uses of a product and the *realized* use experience. Does pre-use affordance have an impact on the way in which users perceive the product in the realized use experience? More precisely, does affordance have an impact on the perception of the performance of the product once placed in use? As we will show, these questions may have great relevance for the design of successful and user-friendly products.

In a preliminary step, let us introduce a distinction between two affordance phases. In the first phase, the user figures out how the object is likely to work and how one should interact with it in order to obtain a given result. In the second phase, the user tries to formulate conjectures about the likely result of the interaction.

Let us take the classical example of a chair. Seeing for the first time a chair-like object, the user understands how she can interact with the object, that is, where she has to sit, place her back, position her hands. Only in the second phase does the user formulate a conjecture about the load the chair can support. If she figures out that the weight to be placed on the chair exceeds the likely maximum load capacity of the object, then the user will opt out. In the last case, the user might prefer a less comfortable but stronger object than that chair. Even if the chair can support, say, twice the weight placed on it, but it appears to be weak, the user might want to use a different and stronger object (e.g. a table). This example shows how the expectations generated before the realized use experience of the product may shape the choice of the user.

The distinction between the two phases of the affordance can be framed in the functional language: in the preliminary phase, the affordance refers to the expectation about the generic function of the artifact (=to let people sit), while in the second phase the expectation refers to the performance in implementing the generic function (=to let people sit, but only if below a given weight threshold).

Now suppose that the user believes that both expectations are satisfied: the object can indeed support people sitting (=implement the generic function of sittability) and can implement the function with an expected level of performance (=implement the generic function of sittability for a person of a given weight), then the user will use the object. If on the contrary, the expected level of performance is not implemented in the generic function, the chair will break apart and the user will experience a failure and perhaps suffer damages.

Despite the importance of these concepts, little is known about their empirical importance in the design context. We have therefore initiated a research program aimed at validating the concepts from an empirical point of view and developing in great detail their implications for the design and new product development practices. More specifically we address the following exploratory research questions.

First, do users perceive expectations of performance in a distinct and separate way from the generic affordance? Is the conceptual construct "expectation of performance" valid? In other words, does our distinction between the expected generic function and the expected level of performance hold within the overall experience of affordance?

Second, conditional on the validity of the construct, do users maintain their performance expectations after the realized use experience of the product?
Third, conditional on the persistence of the expectations of performance after the realized use experience, what is the impact of the perceived difference between expected and realized performance?
In order to address these questions we have to solve two methodological challenges. On the one hand, we have to clearly distinguish between the generic function of a product and its performance. This is done by submitting to experimental subjects a product for which the affordance on the generic function is trivial, so that the focus is exclusively on the dimensions of performance. On the other hand, we have to consider the issue of *perceptibility* of performance. Some dimensions of performance are easy to evaluate during the ordinary interaction with the product, while others are hard to evaluate. Take the classical example of the performance of a car: the acceleration is easy to evaluate during a trial, while the protection of the driver from a crash is very hard to evaluate. In practice, it cannot be evaluated before the purchase (unless the car dealer wants to accept bankruptcy) and it is also not evaluated at all during the lifetime of the product in most cases. This distinction, which is standard in marketing science and economic theory (i.e. experience goods) does not have an analytical treatment, to the best of our knowledge, in engineering design theory. We address it experimentally by submitting to our experimental subjects dimensions of performance with largely variable degrees of perceptibility, so that we can observe the differences in responses.
The paper is organized as follows. Section 2 develops the state of the art of the studies on affordance. Section 3 introduces the experimental setting. Section 4 discusses the results, while the final section develops some implications for the engineering design theory and for management of innovation.

2 STATE OF THE ART

The author that coined the term "affordance" was James J. Gibson (Gibson, 1979), a perceptual psychologist. Later Donald A. Norman applied for the first time the concept of affordance to design (Massaro, 1990). Norman showed how some objects afford a particular use while prevent alternative ones. He gave some examples of affordance of ordinary objects: "A chair affords (is for) support and, therefore, affords sitting", "A glass is for seeing through, and for breaking", "Knobs are for turning", but he also added: "Wood is normally used for solidity, opacity, support or carving".
It must be noted that Gibson and Norman do not give the same meaning to the term affordance.
For Gibson affordances are "offerings" or "action possibilities" in the environment in relation to the action capabilities of an actor. On the contrary, for Norman affordances are "perceived properties" that suggest how to use the product: they may (but also may *not*) actually exist in the real world.
The difference between these two perspectives (let us label them the *ecologist* and the *designer* perspectives) can be better understood if we remove the objects from a visible environment. For both authors there exists a notion such as the "sit-ability" of a chair in a visible environment. However, if this chair is moved to a totally dark room where a person cannot perceive its existence, for Gibson the affordance "sit-ability" is still useful as long as it exists (it can support the weight of the person without any change of the environment); while according to Norman, in this situation the actor cannot perceive the "sitting on the chair," and hence "sit-ability" is useless (unless perhaps the person accidentally touches the chair or turns the light on). In order to resolve this ambiguity Gaver (1991) suggested a four-types classification. Similarly, to Gibson and Gaver (1991) considers affordance independent from the perceptual information and, similarly to Norman, argues that only the affordances that can be perceived are useful. Therefore, he was forced to introduce two new concepts, not discussed here, i.e. the concepts of *false affordance* and *hidden affordance*.
More recently Kannengiesser and Gero (2012) and Spreafico et al. (2015) proposed the Function-Behavior-Structure (FBS) model simulating the view of designers. This model integrates the cognition of users, their perceptions and the environment into a three-layered world, moving from the specific to the universal and suggesting that affordances are generated in the Behavior-Structure domains. The FBS model represents the steps of new product design as a continuous process, comparing the designer's expectations with the practical operations of users and the behaviors and functions of the structure. Based on the FBS model, Cascini et al. (2010, 2013) focused their attention on the misalignment between the expectations of the user and the practical use of the product, resulting in misuses, alternative uses and failed uses.

An important contribution to the development of the theory of affordance has been offered by Maier and Fadel (2003). They tried to extend the application of affordance to the whole design world and not just to some objects, as initially suggested by Norman. They introduced two different conceptual categories: Artifact-User Affordance and Artifact-Artifact Affordance. The former, which is more relevant to our discussion, refers to the interaction between product and user. For them the Artifact-User Affordance is a characteristic neither of the object nor of the human. They also distinguished between the set of all the possible interactions and the subset that are to be considered affordances. Starting from these considerations they defined affordance as "the set of interactions between artifact and user in which properties of the artifact are or may be perceived by the user as potential uses. The artifact is said *to afford* those uses to the user."

The affordance type of interaction is first perceptual; it may also require cognition. The perception of affordance requires some kind of sensory information. For example, through the visual perception a person can understand whether a chair affords sit-ability, or through the tactile perception she can say if an object afford stability. It is clear how every sense could be involved in perceiving affordances.

In a subsequent paper, Maier and Fadel (2008) defined some important properties of the affordances: *Complementarity, Polarity; Multiplicity; Quality; Form dependence*. Let us focus on *Polarity* ("affordances can either be for good or for ill. Positive affordances are potentially beneficial to the user, while negative affordances are potentially harmful") and *Quality* ("a system may possess an affordance, there is still room to describe how well the system affords that specific use or behavior in terms of quality"). They suggest that the overall perception of affordance can be analytically examined by introducing internal distinctions, one based on the sign of the affordance (positive/negative), the other based on the intensity or quality (how positive).

We build upon the contribution by Maier and Fadel (2008) in order to examine in more detail the issue of quality of positive affordance of products. We suggest a slightly different terminology, one that can be easily reconciled with the notion of "quality", by speaking of affordance related to the "performance" of the product. As already stated, we also suggest that another property of affordances may be relevant, i.e. the discernibility of detectability. If affordances, as most authors recognize, mobilize perceptual and cognitive activities, they must be examined in relations to the way in which humans may have access to the physical appearance of products.

We give a contribution to the literature by initiating an experimental program aimed at empirically validating the main properties of affordances highlighted in the literature and developing deeper implications for design theory and practice.

3 EXPERIMENTAL SET-UP

In order to investigate the validity of the construct "affordance of product performance" we designed an experimental setting. First, we selected a category of products of common, but not daily, use, characterized by a relatively small set of performance dimensions, i.e. flashlights. For these products the affordance on the generic function is trivial, i.e. emitting light. Consequently, the cognitive focus of subjects is on the dimensions of performance (or, to use the Maier and Fadel's terminology, on the quality of the positive affordance). We submitted four flashlights to our experimental subjects. The products were selected in such a way that a couple of them had exactly the same level of performance for one of the dimensions (two have the same light, two the same weight and two the same battery duration: see below the details).

Second, we randomly selected a sample of experimental subjects by addressing undergraduate students walking around campus shops at Clemson University, South Carolina, USA. We obtained collaboration from more than half of the students addressed (response rate 60%). The students were requested to give a score to the four flashlights before and after the interaction with the product.

Three different dimensions of performance have been chosen: *light*, *weight* and battery life.

Figure 1. The four flashlights used in the experiment

While *Light* can be evaluated based on sight and *Weight* can be evaluated after touch, the *Battery life* is very hard to be evaluated during the test. We needed products with largely different physical features, in order to maximize the potential for affordance inferences by the subjects. We therefore selected the products A, B, C and D (Figure 1). Unfortunately, four different flashlights with completely different appearance but with exactly the same level of performance do not exist in the market.
Therefore, after the purchase, the LEDs and the electronic circuit of products A and D have been modified to have the same luminous intensity and beam shape.
In turn, the electric consumption of B and C has been measured and the batteries have been chosen in order to have the same battery life for product B and C.
Finally, additional weight has been added to product C in order to weigh as much as product D.
The result is a group of four flashlights in which at least two of them share the same level of performance for each of the dimensions of performance (see Table 1).

Table 1. Comparative table of the 4 flashlights (in bold the characteristics with the same performance in different products; between brackets the unit of measurement)

Product	Light (lumen)	Battery Life (hours)	Weight (lb)
A	**8**	125	1.235
B	10	**5**	0.130
C	35	**5**	**0.275**
D	**8**	25	**0.275**

The experiment was conducted at different locations inside the Clemson University's campus during night time. Environmental conditions were the same for all the experiments. We carefully controlled the following parameters:

- Light (flashlights should be clearly observable, but at the same time also their lights should be easily observable and assessable).
- Target Surface (the experiments were performed at the same distance and in the same brightness/ darkness conditions).

The products were submitted to experimental subjects using a bench located close to switched-on street lamps, during night time. All street lamps produced the same light with the same color and the flashlight position was always the same. In total 112 individuals (almost all of them were students; age between 18-30; one third female, two third male) answered to the questionnaire. Walking in-campus during night time is common practice among students.

4 EXPERIMENTAL RESULTS

4.1 Expectations about performance

Table 2 shows the non-standardized scores for each product and performance dimension. These scores have been first normalized in order to wipe out the variability induced by the subjective scoring procedure in terms of the scoring scale. The individual scores have then been divided by the maximum value assigned to any given performance dimension by the experimental subjects. The normalized data have then been standardized in order to obtain a distribution with mean zero (see the sum of values in columns 4, 5 and 6).
These scores have been assigned to products before any experience with them, that is, upon inspection of their physical features only.

Table 2. Average score for each product and performance dimension. Non-standardized and standardized values

	Mean score			Mean score (standardized)			Standard deviation of the mean (standardized)		
Product	Light	Battery	Weight	Light	Battery	Weight	Light	Battery	Weight
A	6.5	6.6	6.8	0.29	0.24	0.96	0.10	0.11	0.06
B	4.4	4.9	2.0	-0.75	-0.50	-1.27	0.09	0.10	0.04
C	6.5	6.3	4.9	0.40	0.24	0.20	0.08	0.07	0.07
D	6.0	6.1	4.9	0.06	0.02	0.11	0.07	0.08	0.05

The goal is to determine whether there is a common perception among people about the performance of the products before entering into interaction with them. Here respondents could only reason based on the physical appearance of products, as visible on a bench under similar conditions of light. For example, product B is much smaller than other products (back to Figure 5). People apparently infer from this physical feature of the product several clear expectations about its weight (score 2.0, or -1.27 standardized score), the duration of the battery (score 4.9, or -0.50), and even the light (score 4,4, or -0.75). Are these expectations found across all products and performance dimensions?
Let us develop a formal research hypothesis, that is, a null hypothesis. If there is no common perception, the average values for any given performance dimension should not be statistically different across products. In other words, in standardized data we should not find an average value which is statistically different from zero. The null hypothesis (H1) is therefore as follows: *there is no common perception between people so that the difference between the averages is not statistically significant.* To test this hypothesis the p-values have been computed (Table 3).

Table 3. p-values of the distributions of the products scores

Characteristics	p-value	F-Fisher
Light	0.256	1.29
Battery life	0.828	0.048
Weight	**0.0099**	6.71

The results are not significant excepting for the weight. Therefore, we can affirm that the null hypothesis (H1) is rejected for one performance dimension (weight), while it cannot be rejected for two performance dimensions (light and battery life).

We find partial support to our notion of affordance on the performance dimension. The only dimension for which we find confirmation (i.e. we can reject the null hypothesis) is the one for which inferences based on the observation of the physical appearance are more robust. People mentally calculate the weight of products, assuming similar raw materials based on similar appearances (plastic material), largely on the basis of the volume of the product.
When making inferences from the size to the power of light, or to the duration of batteries, their expectations are not systematically correlated.

4.2 Impact of expectations about performance on perceived product experience

In order to understand whether the affordance of product performance has an impact on the scores of the perceived performances, we analyze the changes in preferences of the users after the interaction with the product. [1] For this analysis we used only the scores of products with exactly the same performances (the couple A-D for light; B-C for battery life; C-D for weight in Table 1). We consider the difference before interaction and the difference after interaction with the product. Since the couples have the *same* performance, after testing them, the second difference should be zero. Therefore, we want to understand (i) whether the second difference is zero or not and, in case it is not zero, (ii) what is the sign of the difference. Actually, a positive difference could be sign of a perception driven by the affordance, if negative a perception affected by excessive expectations due to guessed performance. The difference is calculated as (score of the first product) minus (score of the second product) for each couple. It means that the sign of the subtraction indicates the preference: if the sign is positive, the person prefers the first product otherwise the preferred one is the second. Since we are interested in understanding whether an impact does exist rather than in quantifying it, we use only two possible values: +1 in case the preferred product is the first one and -1 if it is the second one.
When one of the two differences is equal to 0 the data are discarded since it is not possible to affirm if the affordance exists (affordance=0) or identify its impact on the final perception (performance=0).
The null hypothesis H2 *is that affordance has no impact on the perceived performance*. Two additional remarks are now necessary before continuing.
Remark 1*:* If the performances of the products are the same and there is no impact of the affordance on the final perceived performance (previous hypothesis), the probability that a person thinks that product B has a higher performance than product C, *after* the interaction, is equal to the probability that he/she thinks that product C has a higher performance than product B (remember that the case in which the two products obtain the same score is not considered). We define *change of preference* the situation in which a person before the interaction believes that product A has a higher performance than product B and then, after the interaction, he/she changes opinion and believes that product B has a higher performance than product A. Conversely *confirmation of preference* is the situation in which a person maintains the same opinion on the performance of the same products (A or B) before and after the interaction.
Remark 2*:* We can infer from *Remark 1* and from the first hypothesis H1 (affordance has no impact on the final perception) that, if the two products have the same realized performance, change and confirmation of preference happens with the same probability. Therefore, it is necessary to determine the number of changes and confirmations of preference. According to *Remark 2,* for each characteristic, only the two products with the same performance are considered. We carry out the following operations:

1. For each characteristic the values of Affordance and Perceived Performance for each person have been calculated.
2. We indicate with 1 if their product is positive (+1*+1 or -1*-1), that means the person does not change his mind (confirmation of preference), -1 if the product is negative (+1*-1, or -1*+1), that means the person changes his mind (change of preference) and 0 if at least one of the judgments (before or after) is the same for the two products.

Moreover, it is important to know whether this difference is statistically significant. Considering that the variables may assume only two states (confirm or change) a χ^2 chi-square test with 1 degree of freedom has been performed in order to determine the p-values. The results are shown in Table 4.

[1] Note that in this context by "preference" we only mean "give a higher (lower) score", without any reference to the economic meaning of preferences.

Table 4. Number of confirmation of preference and number of change of preference and p-value for each characteristic

Characteristics	Number of confirmations of preference	Number of changes of preference	Chi-square	p-value
Light	48	38	1.16	0.2809
Battery	48	29	4.69	**0.0304**
Weight	33	22	2.20	0.138
Total	129	89	7.34	**0.0067**

Two results are interesting. First, for the battery life the difference is statistically significant (p-value 0.0304). Second, the affordance of product performance has a positive impact on the final perception in general (last row, p-value 0.0067): actually the number of confirmations always exceeds the number of changes for all the characteristics.

4.3 Relationship between the performance values

In order to identify potential relations between the variables, we create the differences matrix. This includes all differences before and after the interaction, for each dimension of performance and product, for each respondent. We calculate the correlation between the rows of the matrix. Results show that the most important correlations (in this case positive) are between light and battery life.

In order to investigate better this phenomenon, we conduct further analysis on this couple of performance dimensions. This analysis is similar to the previous one used to prove the existence of the affordance. The hypothesis H3 is that *change in light perception does not cause change in battery life perception*.

We call interaction change the difference between the score after the interaction and the score before the interaction, for each person. We call positive correlation the case in which both light and life of the battery have an interaction change with the same sign (both negative or positive), for the same person. We call negative correlation the cases in which light and life of the battery have an interaction change with opposite sign, for the same person.

We can infer from the hypothesis that, since there are no significant relation between the two variables, the probability to have a positive correlation is equal to the probability to have a negative correlation and so equal to 0.5 for each person. So, for each characteristic and for each product we calculate the interaction change for each person. Then we calculate the product of the two differences. Finally, we indicate with 1 if the product of the differences is positive, this means that the person changes in the same way the two scores (positive correlation), -1 if the product is negative, which means that the person changes in the opposite way the two scores (negative correlation). The results of our first part of the analysis are shown in Table 5. As we can see the number of positive correlations is always larger than the number of negative correlations.

We want to determine whether this difference is statistically significant. Thus, we need to understand if it is true that the change in the score assigned to light has a positive impact on the score assigned to life of the battery. Considering that our variable can assume only two states (positive or negative) we use a binomial distribution and we want to calculate the p-value of our hypothesis. Since all the results show that positive correlations are more than negative correlations, we consider the value of the p-value equal to the probability to obtain a number of positive correlations higher or equal to the one we have obtained. To use the binomial distribution, we have to identify the size of the population. We place this number equal to the sum of positive and negative correlations. To further investigate the significance of this measure we conduct a χ^2 chi-square test. The results are illustrated in Table 5.

Table 5. Number of positive correlation and number of negative correlation and p-value for each product

Product	Positive correlation	Negative correlation	χ^2	p-value
A	40	29	1.75	0.1854
B	46	30	3.36	0.066
C	58	26	12.19	**0.0005**
D	53	24	10.92	**0.001**
Total	197	109	25.35	**0.0000005**

As the results show, the overall significance of the effect is statistically very strong (p-value lower than 1 over one thousand). Only for product A the difference between positive and negative correlations is not significant. For product A the difference is significant, although at less than 10% interval, while for products C and D the statistical significance is extremely high.
Therefore we can conclude that for the four flashlights of the experiments the change in the perception of the light has a positive impact on the perception of the duration of the battery perception. There is a positive relation between these two variables.

5 DISCUSSION AND CONCLUSIONS

We summarize the findings as follows.
First, we find empirical confirmation of the existence of affordances related to specific dimensions of performance of products, or, in other words, related to the quality of affordances (Maier and Fadel, 2008).
Second, users are conservative in formulating their affordances. In the case of flashlights they show affordances related to the performance dimension more closely related to the physical appearance of the product (weight, closely related to size), while affordances do not appear systematically for those performance dimensions that are more difficult to infer from the appearance (light) or are even impossible to infer before the prolonged use (battery duration). In this perspective, users exhibit substantive rationality.
Third, users tend to maintain their affordances even after the use experience. This effect is stronger in the case of dimensions of performance that are more difficult to evaluate, such as battery life.
Finally, and perhaps more interestingly, there is significant interaction among the changes in perception across the performance dimensions. More specifically, changes in the perception of light after the use experience bring with them changes *in the same direction* in the perception of battery duration. This effect is very important. It shows that there are *interactions* in the changes in perception of the dimensions of performance before and after use. This effect has never been demonstrated before in the literature on affordances. It seems to be so strong that it generates a clear violation of principles of rationality. People approximate the perception of those dimensions of performance for which they have less information (battery life) by using information on direct post-use experience on other dimensions that are more observable (light). If they revise upward their expectations on light performance, they tend to believe that products will also perform well in the other dimension, battery life. But this violates obvious engineering constraints: given the amount of energy stored in a battery, the more light it allow to emit, the lower the residual life. This lack of congruence is not noted by users, who seem to be subject to an attraction effect.
This finding is very strong and deserves further research, for validating it, but also for linking it to the literature on decision theory and consumer choice.

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