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ORIGINAL ARTICLE

Is a letterbox always a letterbox? The role of affordances in guiding perceptual categorization

Fabrice Da Silva[1] · Thomas Camus[2] · Denis Brouillet[1] · Manuel Jimenez[1] · Emmanuel Viglieno[1] · Lionel Brunel[1]

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Abstract

Classically investigated in the context of judgment tasks about achievable actions, affordances have also been investigated in the context of the stimulus–response compatibility paradigm. Earlier work showed that perceptual categorization performance is significantly faster and more accurate when the orientation of the graspable part of a presented object, and the orientation of the participant's response are compatible, suggesting that the main function of affordances is restricted to action preparation. Here, we investigate the potential role of affordances in the categorization of ambiguous stimuli through a stimulus–response compatibility paradigm. In other words, we investigate if in ambiguous situations, such as ones in which a stimulus may give rise to two percepts, affordances would stabilize perception on one of these two and, therefore, helps in the subsequent categorizations. Two experiments were run, based on the forced-choice stimulus–response compatibility (SRC) paradigm, with a progressive series of ambiguous (bistable) lateral-graspable objects. In Experiment 1, subjects responded by pressing horizontally opposite keyboard keys, while in Experiment 2, the keyboard keys were vertically separated. Experiment 1 found that subjects perceived the initial object in a bistable series for longer, and exhibited greater response stability in compatible than incompatible situations. In Experiment 2, none of these modulations were significant. Overall, our results show that affordances operationalized through a SRC paradigm modulated how subjects categorized ambiguous stimuli. We argue that affordances may play a substantial role in ambiguous contexts by reducing the uncertainty of such situations.

Introduction

In his ecological approach to visual perception, Gibson (1979) defined *affordances* in terms of the possibilities for action offered directly by the environment. He argued that objects afford different activities depending on the perceiver's physical capabilities. Therefore, affordances are a function of the interaction between the characteristics of an object and a subject. Consequently, a chair affords different actions depending on the perceiver's capabilities (e.g., something to sit on, for a human being; something to sleep on, for a cat). Furthermore, he argued that all affordances exist simultaneously, regardless of whether or not they are perceived. Consequently, objects always afford the same actions. This implies that perceiving an affordance is unrelated to an object's categorization. For instance, a letterbox remains a letterbox—whether or not we need to post a letter. This paper challenges this realistic view by proposing that affordances perception might depend on the subject needs and thus, would vary with regard to the perceiver's disposition to act. Consequently, we argue that affordances related to an object could be a function of its categorization. Hence, the letterbox would be a letterbox only when the perceiver wants to use it as such.

In the field of experimental psychology, two experimental approaches have classically been used to investigate affordances. The first, related to the perceptual control of behavior, consists of experiments in which subjects have to make a decision about the feasibility of specific actions with respect to stimuli characteristics. For instance, Warren (1984) asked participants to make a judgement about the climbability of a stairway. The results of this study revealed that functional perceptual categories ("climbable" vs "unclimbable") could be predicted by a biomechanical model of critical riser height, suggesting that subjects made their judgements based on the actual length of their legs.

✉ Fabrice Da Silva
fabriceds@gmail.com

1 Epsylon Laboratory, Paul Valery University, Université Montpellier Paul Valéry, St Charles, 34 Route de Mende, 34190 Montpellier Cedex 5, France

2 Department of Psychology III, Julius Maximilians University of Würzburg, Würzburg, Germany

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Similar results were found concerning the visual perception of the "passability" of apertures, indicating that subjects take account of their own body size to make such judgements (Warren & Whang, 1987). Similar effects have been observed in many experiments that ask subjects to make a judgement about the feasibility of specific actions. (e.g., "crossing through a gap", Burton & McGowan, 1997; "passing without bending", Marcilly & Luyat, 2008; "stepping over", Kingsnorth & Schmuckler, 2000; "ducking", van der Meer, 1997). Overall, these works suggest that the perception of the possibility of carrying out an action implies taking into account the physical characteristics of the observer. This body-scaled feasibility perception is in line with the Gibson definition of visual affordances.

In the second experimental approach, affordances have been investigated using the Stimulus–Response Compatibility (SRC) paradigm (e.g., Michaels, 1988; Tucker & Ellis, 1998, 2001). Typically, participants engage in a perceptual categorization task by performing an action, and the experiment investigates the motor response associated with the way the presented object is handled depending on its configuration. For instance, Tucker and Ellis (1998) showed that participants categorized the orientation (i.e., upright or upside down) of common objects more quickly and accurately when the object and the motor response were compatible than when they were incompatible. Similarly, the perception of an affordance (e.g., the graspability of an object) has usually been investigated through the manipulation of stimuli characteristics (e.g., the orientation of the graspable part) and potentiated reach-to-grasp gestures. Subsequently, significant experimental effort has been dedicated to studying: (1) the conditions giving rise to affordances (Borghi, Flumini, Natraj, & Wheaton, 2012; Girardi, Lindemann, & Bekkering, 2010; Makris, Hadar, & Yarrow, 2013); (2) the consequences of affordances on motor planning (Makris, Hadar, & Yarrow, 2011; Regia-Corte & Luyat, 2004; Yang & Beilock, 2011); and (3) the underlying neurological substrates (e.g., Cisek, 2007).

Affordances has been widely discussed in the literature and is still being debated today. Many authors dedicated themselves to redefine the concept. (e.g., Stoffregen, 2004; Turvey, 1992). These intense discussions mainly focus on the respective implications of the subject and his environment in the "emergence" of affordances. Some authors claim that affordances are a part of ontological ecology and should hence be considered independently of the perceiver needs and intentions (Michaels, 2003) while others argue that they should be understood as properties of the animal–environment relationship (Chemero, 2003; Stoffregen, 2003). More recently, Morgagni (2009) discussed the possibility that affordances may emerge from phenomenological dynamics implying that affordances are responses to a conceivable practicable action for the subject and thus, depend on his practical knowledges. Other works have sought to broaden the understanding of the concept for heuristic purposes, notably by questioning the extent to which affordances invite actions for a subject. For instance, Withagen, Araújo, and Poel (2017) proposed a dynamic model to account for the modulation of a subject's invitation to act. Starting from the idea that behavior emerges from the interaction between the agent and his/her environment, the authors propose that affordance effects should be understood with respect to the agency of the subject, i.e. their capacity to modulate their coupling with the environment.

The question of a subject's disposition to *respond* to environmental demands (i.e. affordances) has been also discussed by Dings (2017). In this interesting article, the author discusses several phenomenological implications associated with the concept of affordances; more specifically *how* affordances should solicit—or not—actions for a subject, and what could be the experiential differences that make an affordance phenomenologically "present" for him/her. These examples show that the concept of affordances has led to numerous perspectives, some of which are consistent with the original position taken by Gibson (1979), while others are very different. As a result, the concept has taken a multitude of meanings and the literature has become a bit confusing (Osiurak et al., 2017). In our opinion, this confusion might have emerged from inconsistencies resulting of the realistic approach adopted by Gibson (1966) when describing affordances. In the following section, we discuss one of these inconsistencies, notably between affordances and categorization.

Following Gibson (1979), perceiving an affordance and categorizing an object should be unrelated because objects are classified (i.e., categorized) in terms of common features and given arbitrary names. As a consequence, an object (e.g., a letterbox) can be the subject of different actions (e.g., to post a letter in the aperture or to place an object above the box), without implying different categorizations. Moreover, Gibson (op. cit.) concluded that the arbitrary names given to objects are irrelevant for perception. However, this assertion can be confusing because, in this case, categorization relates exclusively to the consensual designation of the object. On the other hand, if we consider categorization as the action of distinguishing a specific object from similar others in a given environment, the question of a relation between affordances and categorization may become relevant. For instance, animals lack language but must quickly categorize surrounding objects to avoid danger and ensure their survival. Many of these objects are visually perceived, and any mistake can be deadly. In these contexts, it is reasonable to assume that the actions afforded by the surrounding objects are necessary for their categorization (e.g. to shun it or not).

There is no reason to believe that human beings perceive and act differently, even when they can clearly designate the objects they encounter.

This question has not received much attention (Withagen & Chemero, 2012). Experimental psychologists have mostly limited themselves to demonstrate that the perception of affordances influences performances in categorization tasks (Michaels, 1988; Tucker & Ellis, 1998, 2001), or the perception of control in specific actions (e.g., Warren, 1984). Consequently, the role of affordances has been mainly considered in terms of preparation to take action in experimental works: perceiving an object's affordance is expected to favor the selection of the best response associated with it. Similarly, responding to a letterbox with a gesture compatible with the movement of posting should facilitate the letterbox response, but not impact the category associated with this stimulus. Therefore, Gibson's ecological approach suggests that affordance perception would seem to be unrelated to any kind of categorization. This assertion appears as a logic consequence of the theory of direct perception he defended (Gibson, 1979). Hence, visual objects would specify what they are in the ambient array of light (energy patterns).

Nevertheless, a problem of this direct specification is that it does not provide any insight on involved perceptual mechanisms. Because visual information is understood as being fully informative, little attention is paid to understand the implication of the perceiver's state. Affordances are always there and it is up to the subject to perceive them or not. Yet, some recent theoretical and experimental elements are likely to question this assertion. For instance, it has been discussed that stimuli and action plans seem to be represented in a common format through sensory-motor units. This would imply that stimulus event and action plans are not qualitatively different (Hommel, 2013). Consequently, when a perceiver has to perform actions to or with an object, modulations of relevant feature dimensions are applied to the stimulus with regard to the intended actions. Considering that visual perception always involves actions (realized or to be carried out) in ecological situations, it is, therefore, reasonable to assume that visual stimuli (and related affordances) are not processed identically for all subjects and in all situations. Such differences in affordance perception emerge from several dimensions such as the visual context (Kalénine et al., 2013), the perceiver expertise (Weast et al., 2008; Weast, Shockley & Riley, 2011), the anticipated cost of the action (Proffitt, 2006), or even from aesthetic criteria (Xenakis & Arnellos, 2013). These differences could emerge during visual processing and more specifically, from the modulation of the weight of relevant feature dimensions for action. Indeed, it has been shown that object-action priming seems to be constrained by processes of perceptual selection (Makris et al., 2013). This perceptual selection would depend on the purpose of the perceiver. Thus, when perceiving an object, visual processing would be constrained by what is to be done with it.

Hence, it seems that light patterns alone could not be sufficiently informative to explain many experimental results. Moreover, other particular situations are even further problematics; namely, when objects are insufficiently specified by light patterns. These situations correspond to what we call *perceptual ambiguity*, and to what Gibson referred to when he wrote that "a thing may not look like what it is" (Gibson, 1979). In these particular situations, categorization may be crucial to inform the subject. This question has been discussed by Withagen and Chemero (2012) who proposed that categorization could be a direct process implying that it may not necessarily imply high-level cognitive processes. Withagen and Chemero (2012) write that "classes do not have determinate boundaries, the similarities and relationships among the members of the class imply that there are patterns in the array that correlate with classes but are not specific to them" (Withagen & Chemero, 2012, p. 13). However, if light patterns only correlate with classes, some additional clues should be involved to explain humans and animal performances in categorizing stimuli in ambiguous situations. The purpose of this paper is to highlight that affordances could represent such clues in visual ambiguous situations. Operationally, they could stabilize perception on classes of objects in situations wherein these classes are associated with congruent stimulus–response situations. These situations would represent an evidence that relevant information might extend beyond visual properties (made available by the ambient light array) to action-related properties (with respect of the subject intention and disposition to act). In this case, responding to an object with a particular gesture (e.g., posting) could directly contribute to its categorization (e.g., a letterbox) by strengthening perceived action-related features.

However, testing this assertion is difficult, for several reasons. First, in the context of arriving at a judgement about achievable actions (e.g., Warren, 1984), the aim has been to highlight perceptual modulations between achievable and non-achievable actions. Here, the presented objects or surface remained unchanged for subjects and only their perception of the possibility of carrying out specific actions differed. Second, in the context of forced-choice categorization tasks, most research has used chronometric measures. As a consequence, results systematically reported mean reaction time differences between compatible and incompatible situations. If we assume that perceiving an affordance could be relevant to its categorization, chronometric measures are insufficiently informative, because they do not provide any insight regarding *what* is perceived. Furthermore, in the standard SRC paradigm, stimuli are univocal, which limits the use of non-chronometric measures and prevents additional investigations of responses. For instance, Tucker and

Ellis (1998) showed that participants produced fewer errors when categorizing the object in compatible (e.g., upright compared to upside-down), than incompatible situations. However, it remains unclear whether these miscategorizations reflected an incorrect perception (e.g., participants perceived the object as upright), or an incorrect response (e.g., participants perceived the object as upside down but responded as if it was upright).

One way to investigate this question is to use ambiguous stimuli, for which several percepts are possible. In this case, all alternative responses are equally appropriate, and the manipulation of categorizations makes it possible to determine whether affordances can influence what is perceived. This hypothesis was tested by the application of a SRC paradigm (Tucker & Ellis, 1998), based on a progressive (Fisher) series of stimuli (Fig. 1).

Participants performed a perceptual categorization task using visual stimuli depicting graspable objects (see Fig. 1 for an example). Affordances were operationalized in terms of SRC between the object's orientation (i.e., left or right) and response sides (i.e., left or right; see Tucker & Ellis, 1998 for a similar protocol). This allowed us to distinguish between compatible (i.e., response to a right-oriented object using a button on the right-hand side) and incompatible (i.e., response to a right-oriented object using a button on the left-hand side) situations. Perceptual uncertainty was operationalized using bistable stimuli (stimuli for which two percepts can be produced).

Bistability occurs in most sensory modalities (Schwartz, Grimault, Hupé, Moore, & Pressnitzer, 2012) and refers to the perceptual oscillation that occurs when a stimulus has the characteristics of two percepts simultaneously (e.g., the Necker Cube). This oscillation can be controlled by decomposing a bistable image into several other images that share more visual properties with either the first or second percept. When this decomposition is organized into a progressive series, there is a continuous transformation from the first percept to the second. The original Fisher series (Fisher, 1967) consists of 15 images depicting the progressive change from a male face to a female silhouette. The results of continuous categorization tasks show a preservation effect of the first percept (i.e., participants see it for longer, while the second is perceived later), irrespective of the direction of the series (man-to-woman or woman-to-man). Therefore, when observing both directions in a series, the categorization shift (i.e., from one percept to the other) occurs at different images. Tuller, Case, Mingzhou, and Kelso (1994) studied such variations in the categorization of the spoken words "stay" and "say". Their work highlighted three response profiles: *hysteresis*, *enhanced contrast*, and *critical boundary* (Fig. 2). Hysteresis corresponds to the later categorical switch found in ascending series (i.e., the preservation of the initial percept); enhanced contrast corresponds to the opposite (i.e., a 'premature' switch that could be interpreted as the anticipation of the second percept); and the critical boundary corresponds to a category switch located at the same point in both ascending and descending series.

Hysteresis, enhanced contrast and critical boundaries are properties of phase transitions found in non-linear oscillatory systems (Haken, Kelso, & Bunz, 1985). Originally observed in ferromagnetism (Ewing, 1884), hysteresis has been highlighted in various human regulative processes such as the coordination of hand movements (Kelso & Holt, 1981), one-to-two-hand transitions (Lopresti-Goodman, Turvey, & Frank, 2011), speech categorization (Tuller, Case, Mingzhou, & Kelso, 1994) or the perception of apparent motion patterns (Hock, Kelso, & Schöner, 1993). Hysteresis reflects the (cognitive) system's dependence on recent history and could correspond to the need for consistency, despite slight environmental variations. Enhanced contrast (negative hysteresis) is more frequently observed when the perceiver has a lower level of engagement with the relevant

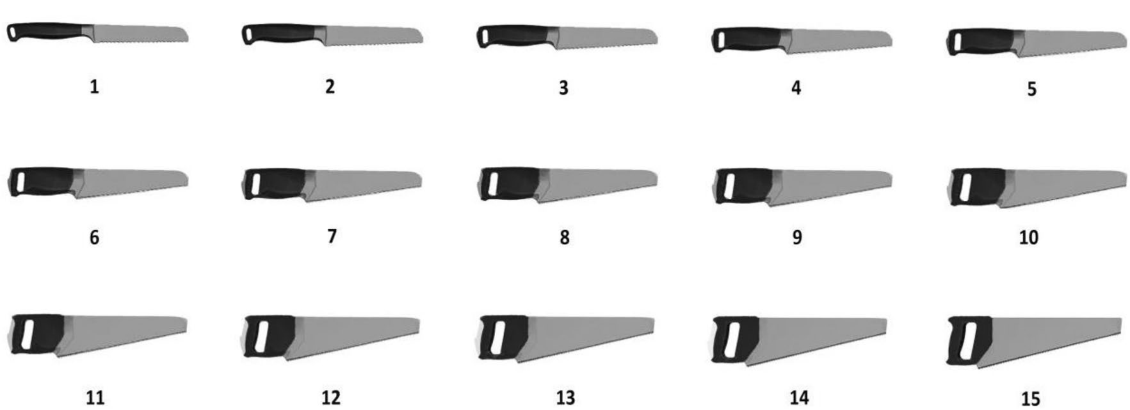

Fig. 1 Example of the morphing series used. A bread knife gradually transforms into a saw. Perceptual ambiguity is highest in the middle of the series (around the eighth image)

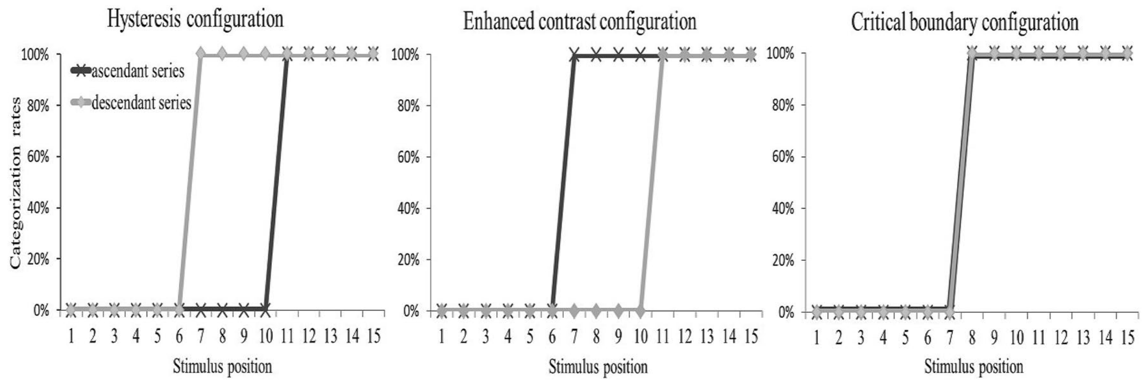

Fig. 2 Three response profiles as a function of categorization rate, the direction of the series, and the relative position of the stimulus. The gap between the switch in ascendant and descendant series determines whether the profile is characterized by hysteresis, enhanced contrast or a critical boundary

object property. For example, subjects who are asked to report verbally on the action afforded (rather than performing it), tend to make the switch between modes earlier (Lopresti-Goodman et al., 2011). Poltoratski and Tong (2014) investigated the dynamic perception of scenes and objects by presenting a progressive transformation between two canonical views. The authors observed a persistent hysteresis effect and argued that it may help disambiguation. This assertion is particularly interesting because, if a pattern of hysteresis is taken as evidence that the cognitive system is engaged in a disambiguation process, variation in the size of the hysteresis effect could be interpreted as an indicator of the subject's ability to disambiguate.

In the present article, we consider hysteresis as an indicator of perceptual stability (Poltoratski & Tong, 2014), and variation in the size of the effect as a modulator of that stability. Therefore, modulation of the conservation effect is operationalized as a measure. Our hypothesis is that compatible stimulus–response situations stabilize perceptions and should result in later categorical switches compared to incompatible ones. Additionally, if this lag appears in both directions of a series, we expect to observe greater hysteresis in compatible, compared to incompatible situations. The first experiment tests this hypothesis in a classical, SRC forced-choice categorization task, using a Fisher-like series of images (Fig. 1). A second experiment tests the participant's response, to explore the effect of the motor situation on the effects observed in the first experiment.

Experiment 1

Ambiguity was operationalized by processed images of everyday, graspable objects, which were selected following pretesting (consistent with the classical SRC paradigm). The results of the pre-test revealed facilitation effects similar to those highlighted by Tucker and Ellis (1998). Participants were able to categorize the four objects more quickly when their graspable parts were on the same side as the response hand. This material was modified to create a series of progressive transformations (i.e., morphing, see Fig. 1). Participants were asked to categorize successive objects as either a kitchen utensil or a garden tool as quickly as possible. Images of objects presented around the midpoint of the series (ambiguous objects) were characterized by the physical properties of both categories. Series were either ascending or descending (Poltoratski & Tong, 2014). Although the physical properties of the object changed, it remained graspable, and its graspable part remained on the same side. Figure 1 shows the transformation of a bread knife (a kitchen utensil), which is graspable on the left, into a saw (a garden tool), which is also graspable on the left.

We predicted that category switches would be modulated by whether series were ascending or descending. This pattern would correspond to the hysteresis effect reflected in a critical change in the subject's behavior depending on the order of presentation of the manipulated parameter (Kelso & Holt, 1981). The difference between the point of the switch in ascending and descending series should determine the magnitude of the hysteresis effect (Fig. 2). Furthermore, we hypothesized that categorical stability would be greater in compatible than incompatible situations, seen in a later switching point. The predicted effect was that hysteresis would increase in compatible situations and decrease (relatively) in incompatible ones.

Method

Participants

The experiment was carried out in accordance with the Code of Ethics of the World Medical Association (the

Helsinki Declaration). Thirty-eight undergraduate students (32 women) from Paul Valery Montpellier University aged from 17 to 48 years old ($M = 22.15$, SD = 7.39) took part and received course credits. All had normal or corrected-to-normal vision and were unaware of the purpose of the study. Six were left-handed and were distributed equally into the two groups of subjects (i.e., corresponding to the counterbalancing between response keys).

Apparatus and materials

The experiment was performed with E-Prime 2 software (Schneider, Eschman, & Zuccolotto, 2002). Materials consisted of two series representing the transformation of one graspable object into another. Morphing software (FantaMorph 5.3.5) was used to create two sets of 15 images: the first represented the transformation of a bread knife into a saw (Fig. 1), and the second the transformation of a teaspoon into a garden shovel. Next, the orientation of the stimulus was reversed to create another set of 15 images (i.e., the graspable part of the object was switched from the left to the right-hand side). Perceptual dimensions (i.e., size, color, contrast and brightness) were adjusted in such a way that the transformation was fluid and progressive.

To limit habituation, two pseudorandom series were produced for pairs of images and orientations, respectively. In these series, morphed images were presented in the order: 15, 1, 3, 14, 2, 12, 13, 5, 11, 4, 6, 10, 7, 9, 8. Thus, the most different images (from the beginning and end of the series) were presented first, and the most ambiguous images (from the middle of the series) were presented last. Pseudorandom series were not analyzed but served to dishabituate participants from the preceding progressive series. Participants responded to the images using an AZERTY keyboard equipped with two keys (i.e., Q and M located in the same place that the A and L keys on QWERTY keyboards) covered by a green or yellow sticker. The two experimental conditions were compatibility and order of presentation.

Design and procedure

Participants received a warning signal indicating the beginning of a new series. For both orientation conditions, they responded by pressing the ‘Q’ key with their left index finger or ‘M’ with their right. Participants were given no feedback regarding their responses, in other words, they were totally free to decide whether they perceived the stimuli as depicting a kitchen utensil or a garden tool. A total of 360 images were presented, consisting of a counterbalanced series of the two orientation conditions (left and right), three orders (ascendant, descendant, and pseudorandom), and the two pairs of objects (bread knife–saw; teaspoon–garden shovel).

Situations in which the graspable part of the object was on the same side as the response hand were considered as compatible. Those in which the graspable part of the object was on the opposite side to the response hand were considered incompatible. Series beginning with the teaspoon (bread knife) were termed ascendant, and those starting with the shovel (saw) were termed descendant. With respect to the order of presentation, both the grasping orientation and the image pair changed in each series. Furthermore, each ascendant or descendant series was separated by one of the two pseudorandom series in which the grasping orientation was reversed. There were two blocks. Each ascendant or descendant series was presented once in the first block, and once in the second. The order of presentation in the second block was the reverse of the first, in order that a series in the first block was never preceded or succeeded by the same series in the second block. Figure 3 depicts one possible example of a test run for the two experiments.

Results

Response configuration

Initial data processing and subsequent analyses were performed using R software (version 3.1.0, R Foundation for Statistical Computing). Raw responses were converted to

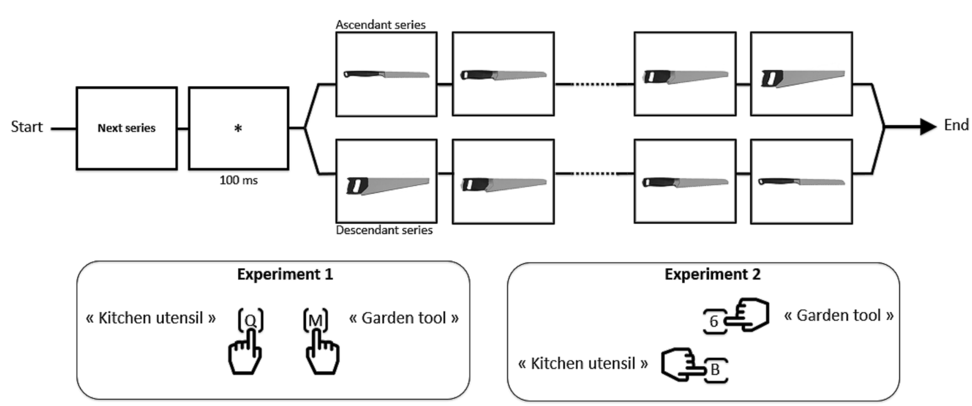

Fig. 3 Example of a test run for the progressive series Knife-Saw. Participants categorized the stimuli with two laterally opposite keys in Experiment 1 and with two vertically opposite keys in Experiment 2

a binary response based on the participant's choice (0 for Kitchen Utensil, 1 for Garden Tool). Images were identified by a numerical value, rather than their relative position in the series: an image had the same number irrespective of whether the series was ascending or descending. Categorical switches were estimated by fitting these data locally using the model free package (Zychaluk & Foster, 2009), giving a point of subjective equality (PSE) for each participant and each experimental condition (i.e., Series direction and Compatibility). This procedure led to the exclusion of three participants due to a lack of data and thus fitting was not possible. The mean switching point was calculated for each experimental condition (i.e., Series direction and Compatibility).

The response configuration was determined by subtracting the mean switching point in a descendant series from mean switching point in ascendant series. Hysteresis corresponded to a positive result (i.e. a lag in switching between the two directions of a series), Critical boundary to a null result (i.e. same switching point in both directions), and Enhanced contrast to a negative result ('premature' switches). Next, we calculated the percentage of responses as a function of compatibility. Table 1 shows that hysteresis dominated in both compatible and incompatible situations. Concerning the three distribution patterns, we aimed to determine whether the stimulus–response compatibility (Compatible vs. Incompatible) was predictive of the response configuration (Hysteresis vs. Enhanced Contrast vs. Critical boundary) or not. We used logistic regression to model the response configuration variable. The model took into account both inter and intra-subject variability. Therefore, the subject was modeled as the random variable, compatibility as the nested, predictive fixed factor, and the response configuration as the parameter to be estimated. The results of this model indicated that stimulus–response compatibility did not significantly predict the response configuration $p > 0.05$. However, descriptive statistics are consistent with our hypothesis. If hysteresis is related to increased perceptual stability, stimulus–response compatibility situations seemed to modulate the response dynamics of the subjects by enhancing categorical stability.

Table 1 Percentage of response configuration as a function of compatibility for Experiment 1

	Hysteresis	Enhanced contrast	Critical boundary
Compatible situation	80.0	17.14	2.86
Incompatible situation	74.29	22.87	2.86
Mean	77.14	20	2.86

Mean switching points

As hysteresis dominates for both compatibility conditions, only series whose performance was consistent (i.e., exhibiting hysteresis) were taken into consideration for the mean switching point analysis (see Table 1). Subjects with no data ($n=1$) or with missing data for or more experimental conditions ($n=4$) were excluded. Thus, the analysis of mean switching points focused on 30 participants allowing to study modulations of the hysteresis effect in progressive series A 2 × 2 (Series [ascendant, descendant] × Compatibility [compatible, incompatible]) repeated-measures ANOVA on mean category switch found a main effect of series (F(1, 29) = 340.6, $p < 0.01$, $\eta^2 p = 0.946$). Participants switched categories significantly later in ascendant ($M = 8.85$, SD = 0.74) than in descendant ($M = 6.05$, SD = 0.83) series, indicative of hysteresis. No main effect was found for compatibility ($F < 1$) Nevertheless, the analysis found a Series × Compatibility interaction (F(1, 29) = 5.37, $p = 0.027$, $\eta^2 = 0.16$), confirming that the switching point was modulated by compatibility and series direction (Figs. 3, 4).

Additionally, we calculated mean switching points for "enhanced contrast" series. As the amount of data (see Table 1) was not sufficient to perform the same analysis as

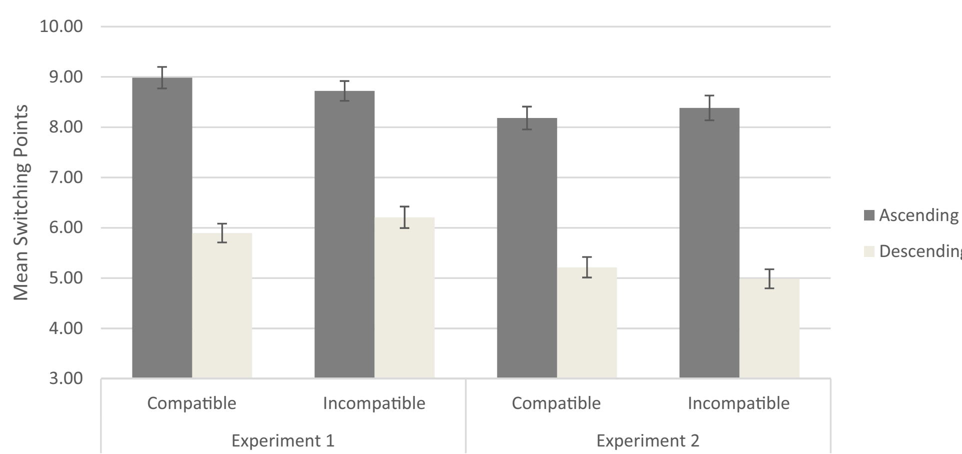

Fig. 4 Mean switching point (the position of the category change) as a function of series direction and compatibility for Experiment 1 and Experiment 2. Error bars indicate standard errors

for "hysteresis" series, we only report descriptive data (see Table 2). Consistently with our hypothesis, we can see that the magnitude of the contrast is larger for the incompatible situation than for compatible situation. This could indicate that incompatible situations led to more instability and then more premature switches (or perceptual anticipation) compared to compatible situations.

Hysteresis

The size of the hysteresis effect was calculated by subtracting the mean switching point (i.e., image number) in the ascendant series from the mean in the descendant series for each compatibility condition. The difference was significant ($t(29) = 2.31$, $p = 0.027$, $d = 0.54$). Specifically, participants continued to categorize objects in the initial perceived category for longer in compatible ($M = 3.08$, SD= 1.15) than incompatible ($M = 2.51$, SD= 0.99) situations. Given Cohen's d and the relatively small size of the sample, we performed a Bayesian paired sample t test to compute the likelihood in favor of the alternative hypothesis over the null hypothesis (i.e. Compatible > Incompatible). For this analysis, we assumed a Cauchy distribution and kept the default width (r scale = 0.707). The Bayes factor (BF10= 1.923, error < 0.001) suggested that the data were 1.923 times more likely to be observed under the alternative hypothesis.

Discussion

The aim of Experiment 1 was to explore the effect of affordances on the categorization of progressively ambiguous stimuli. Percentage of response configuration as a function of compatibility showed that categorization was modulated by compatibility. Specifically, in compatible situations, participants switched categories significantly later than in incompatible situations. In compatible situations, affordances appear to reinforce the initial category to the detriment of the second, to a greater extent than in incompatible situations. Concerning the mean switching points analysis, only stable series showing a hysteresis pattern were considered. Indeed, we were exclusively interested in studying the modulation of the conservative effect (hysteresis) in perception as a function of stimulus–response compatibility situations. Indeed, in the context of visual perception, hysteresis pattern seems to correspond to the subject's need for consistency, despite slight environmental variations. Results showed that compatible situations led to stabilize subject's perception on the first category they were responding.

Table 2 Mean switching points as function of compatibility for "Enhanced contrast series"

	Ascending	Descending	"Enhanced contrast" size
Compatible situation	6.44	7.87	− 1.41
Incompatible situation	6.06	7.84	− 1.77

Affordances are defined as the product of the animal–environment system (Gibson, 1979). If the observed modulations in Experiment 1 were due to the coupling between the subject disposition to act and the motor-related dimensions of the presented stimuli, changes in this disposition should impact the effect. This modulation of the effect preveniently observed should assert that it did emerge from motor-related dimensions.

This hypothesis was tested in a second experiment, which modified the participant's response. The task was the same as in Experiment 1, with the difference that the keys participants were asked to press, were vertically separated, rather than horizontally. The purpose of this manipulation was to impact the quality of the interaction between the subjects and the material. Indeed, SRC facilitation effects have been mainly highlighted in situations wherein subject responses and stimuli configuration were compatible or congruent (in terms of spatial dimension, for instance, see Tucker & Ellis, 1998). Here, the vertical opposition design was intended to create situations in which no such lateral compatibility was involved. By purpose of clarity, we chose to keep the terms "compatible" and "incompatible" but here, exclusively in reference to the response hand and not anymore to the spatial location of this one. This way, the compatible situation corresponded to pressing the lower key with the left hand when the graspable part of the presented object was on the left-hand side and the upper key with the right hand when the graspable part was on the right-hand side. The opposite configurations were considered as incompatible situations.

Experiment 2

Methods

Participants

Thirty-one undergraduate students (26 women) from Paul Valery Montpellier University aged from 18 to 38 years old ($M = 22.41$, SD= 5.01) took part in the experiment and received course credits. All had a normal or corrected-to-normal vision and were unaware of the purpose of the study. Five participants were left handed, and were divided equally across the two groups.

Apparatus and materials

The materials were the same as those used in Experiment 1.

Design and procedure

The protocol was identical to that used in Experiment 1, except for the response orientation. Participants responded using their index fingers. They pressed either the 'B' key with their left index finger or the '6' key with their right index finger on an AZERTY keyboard (i.e., a vertical opposition). A situation was considered to be compatible when the hand used by the participant to respond was on the same side as the grasping part of the object (by egocentric reference but no longer spatially). The hand-side and vertical location were not counterbalanced as we were interested in questioning the role of the coupling between subject's hand opposition and response orientation on the effects observed in Experiment 1. Hence, we aimed at reducing the quality of this coupling by changing the response orientation in this experiment.

Results

Response configuration

As in Experiment 1, categorical switches were estimated by fitting these data locally using the model free package (Zychaluk & Foster, 2009), giving a point of subjective equality (PSE) for each participant and each experimental condition (i.e., Series direction and Compatibility). Here again, mean switching points were calculated as the first image directly following the change in category for each experimental condition and, as in Experiment 1, hysteresis dominated (see Table 3).

Mean switching points

In Experiment 2, hysteresis also dominated in all conditions and, therefore, only series whose performance was consistent (i.e., exhibiting hysteresis) were taken into consideration for the mean switching point analysis. Subjects with missing data ($n=2$) were excluded. Mean switching points were calculated for each compatibility condition. A 2 × 2 (Series [ascendant, descendant] × Compatibility [compatible, incompatible]) repeated-measures ANOVA revealed a main effect of series ($F(1, 28)=206.8$, $p<0.01$, $\eta^2=0.954$).

Table 3 Percentage of response configuration as a function of compatibility for Experiment 2

	Hysteresis	Enhanced contrast	Critical boundary
Compatible situation	93.55	6.45	0
Incompatible situation	93.55	6.45	0
Mean	93.55	6.45	0

Participants switched significantly later in ascendant ($M=8.28$, SD= 1.12) than in descendant ($M=5.10$, SD= 0.83) series. This finding demonstrates the persistence of hysteresis. Concerning the mean switching points as a function of compatibility situations (see Fig. 3), no main effect of compatibility ($F<1$), or Series × Compatibility interaction ($F(1, 28)=2.69$, $p=0.12$) was found.

Contrary to Experiment 1, we did not calculate mean switching points for "enhanced contrast" series, the amount of data (see Table 3) was clearly not sufficient.

Hysteresis

Unlike Experiment 1, a bilateral *t* student test on hysteresis found no significant difference between compatible and incompatible situations ($t(28)=1.63$, $p=0.12$). To compute the likelihood in favor of the null hypothesis over the alternative hypothesis, we performed a non-directional, Bayesian paired *t* test (i.e. Compatible ≠ Incompatible). For this test, we informed the prior odds with the posteriors obtained from the preceding Bayesian paired *t* test ($M = 0.57$, SD=1.37). The Bayes factor (BF01= 2.445) indicated that the data were 2.445 times more likely to be observed under the null hypothesis. Therefore, it seems that in this case, subjects did not perceive the stimulus as belonging to the first category for longer, in compatible compared to incompatible situations.

Hysteresis size comparison between Experiment 1 and Experiment 2

To compare the hysteresis sizes of Experiment 1 and Experiment 2, we performed a 2 × 2 × 2 (Series [ascendant, descendant] × Compatibility [compatible, incompatible] × Response Situation [horizontal opposition situation, vertical opposition situation]) repeated-measures ANOVA with the Response Situation as between factors. Consistently, the test revealed a significant interaction between the three factors, $F(1, 43)=7.344$, $p<0.01$, $\eta^2=0.28$ indicating that the response had modulated the effect. There was none Series × Motor situation interaction and none Compatibility × Motor Situation interaction.

Discussion

Experiment 2 was designed to explore the role of the subject's disposition to act in the effects highlighted in Experiment 1. It aimed to show that this effect was dependent of a sufficient fitness between stimuli orientation (i.e. grasping parts oriented to the left or the right) and the localization of responses (i.e. left and right responses). In Experiment 2, participants responded with two vertical opposite keys implying a less congruent situation of response than in

Experiment 1. Here, no modulation was found when subjects were asked to respond this way. A correspondence between the location of the response and the location of the graspable part of presented object seems to be a substantial factor in the impact of affordances in categorization performance in this kind of tasks.

General discussion

This article aimed to show that affordances play a role in perception in ambiguous situations (i.e., in situations where a stimulus can give rise to various perceptions). Most of the previous work has studied the phenomenon in terms of its impact on action planning (e.g., Tucker & Ellis, 1998, 2001, 2004) or judgments about specific actions (e.g., Warren, 1984, Burton & McGowan, 1997; Marcilly & Luyat, 2008; Kingsnorth & Schmuckler, 2000; van der Meer, 1997). In the case of judgement tasks, research has examined in detail the role of modulation in carrying out specific actions regarding explicit objects (e.g., the possibility of climbing a flight of stairs). In the SRC context, the measures that are typically used (i.e., chronometric), and the univocal characteristics of the presented stimuli have limited analyses to the effect of modulation on specific perceptions.

Our work represents a novel approach. We combined progressive, ambiguous stimuli with the SRC paradigm to show that: (1) affordances can qualitatively impact the categorization of graspable objects (not in terms of achievable actions but regarding the percepts themselves); and (2) successive categorizations seem to be produced by reference to the subject–environment relation. Experiment 1 demonstrated that compatible and incompatible situations resulted in different patterns of categorization. Hysteresis was more evident in compatible situations, while Enhanced Contrast was more frequently found in incompatible situations. This result may reflect variations in the perceiver's engagement with the task. If we formalize this engagement as the "functional distance" between the subject and the relevant property of the object (Lopresti-Goodman et al., 2011, 2013), our findings suggest that it is modulated by the SRC situation. Our results show that compatibility impacts engagement by stabilizing the subject's perception. This is supported by the finding that the size of the hysteresis effect was significantly larger in compatible than incompatible situations. This difference is interesting because it shows that the subject's detection of a change in a series of visual stimuli is modulated by how they must act. Rather than the simple modulation of chronometric performances, it is the way that subjects perceive the stimulus itself that is affected.

Experiment 2 tested whether the effect found in Experiment 1 depended on a congruent response situation regarding the orientation of the stimuli. This experiment was identical to the first, except with regard to the participant's response. Here, neither the distribution of categorical responses nor the size of the hysteresis effect was significantly different.

Overall, these results support our hypothesis of a role of affordances in the categorization of ambiguous stimuli. In our view, understanding the nature of these effects need to consider both the implication of attention and motor control dimensions. When confronting visual stimuli depicting oriented objects, perceivers tend to orient their attention to the graspable part of these objects. This is probably due to the asymmetrical aspect of such parts. Nevertheless, attentional effects alone cannot be explicative of the highlighted effect in this work. Indeed, the orientation of the graspable parts stayed constant in progressive series we confronted the participants with. Consequently, the differences in categorization dynamics could not be explained solely at an attentional level. A more likely scenario would need to consider the implied motor dimensions. As we mentioned it, it has been discussed that stimulus event and action plans could be not qualitatively different (Hommel, 2013). This assertion is based on several experimental studies implying fMRI observations (e.g., Schubotz et al., 2003). The results of these studies showed that subjects would consistently activate the lateral premotor cortex when engaging in judgment about dimensions of graspable objects, even when these dimensions are not related to action. Those observations suggest that action-related brain areas are involved in directing attention toward action-related perceptual dimensions (Schubotz et al., 2003). Consequently, the perceptual system would be particularly sensitive to action related dimensions when facing graspable objects. Therefore, in tasks implying real actions according to action-related dimensions, the cognitive system should be substantially impacted by the spatial congruency or compatibility between the location of both the response and the object. Hence, in visual ambiguous situations, this sensitivity should impact the dynamic of categorization because the cognitive system lacks clues about the presented object. This impact appears at a consequence of the interconnection between actions and perception representations. In this context, it could be interesting to verify if our results could be predicted by a modern connectionist model such as HiTEC (Haazebroek, Raffone, & Hommel, 2017).

The originality of our work is that it highlights qualitative modulations of affordances on perception (i.e., *what* is perceived rather than *how* it is perceived). In a slightly different context, studies have examined whether the perception of one of an object's affordances could affect the detection of another of its affordances (see, for example, Ye, Cardwell, & Mark, 2009) or how objects could be perceived through their affordances when these objects offer several possibilities for action (e.g., Chemero, 2003; Reed, 1996; Rietveld

& Kiverstein, 2014; Stoffregen, 2003, 2004). Overall, these works tend to highlight some limitations of the realistic description of affordances as environment properties.

One of these limitations concerns the assumed independence of affordance perception and categorization (Gibson, 1979). When confronting to visual ambiguous situations, categorization should be crucial to stabilize the perceiver's perception and allow him/her to efficiently react. In our view, perceptual categories can be seen as phenomenological aggregates that emerge from several properties of the situation (see Brunel, Vallet, Riou, Rey, & Versace, 2015; Versace, Vallet, Riou, Lesourd, Labeye & Brunel, 2014), and affordances could be considered as such properties. Therefore, it seems that affordances and categorization cannot be considered as independents. Our results show that in the context of the perception of ambiguous stimuli, affordances seem to stabilize perceptions around the most consistent stimulus with the current perceiver's actions. Returning to the letterbox example (Gibson, 1979), we agree with Gibson that the letterbox is perceived through what it affords but, unlike him, we assume that the letterbox is never the same. Although names are indeed random words used to qualify objects, these words cannot reflect the variability associated with the percept and its expected use. The purpose of labels is, precisely, to synthetically report experience by eliminating variability. Therefore, our study of perceptual ambiguity offers a useful way to investigate such variability. In particular, the use of hysteresis as an indicator of perceptual dynamics seems to be an appropriate way to investigate the variability associated with common perceptions.

Additional studies should investigate the link between affordances and categorical variability. In our experiment, only two responses were possible. A free-choice paradigm with a larger number of responses would shed light on other, potential functional roles of affordances in categorization. A further consideration is that the experimental situation (such as the one used here) is very different to the situations found in daily life. Therefore, attention needs to be paid to creating more ecological situations. This should include more realistic responses (e.g., grasping handles), additional measurement devices (e.g., eye trackers), or the use of a virtual reality environment. Finally, the choice of a single stimulus–response compatibility paradigm limits any conclusions we can draw about affordance perception for disambiguation. Going forward, it will be necessary to investigate this question using judgement tasks that include better measures of the subject's phenomenological experience of the presented situations. Nevertheless, our work is consistent with an integrative approach to perceptual activity. Extensions to our work should broaden the scope of the concept of affordances and emphasize the dynamic coupling between the subject and his ecological and social environment.

Data accessibility Visual stimuli and data files are available at osf.io/sjf4n.

Compliance with ethical standards

Conflict of interest The authors of the present article declare that they have no conflict of interest.

Ethical approval All procedures performed in the present studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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