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# Categorization and sensorimotor interaction with objects

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**Abstract**

Three experiments were aimed at verifying whether the modality of interaction with objects and the goals defined by the task influences the weight of the properties used for categorization. In Experiment 1 we used everyday objects (cups and glasses), in order to exclude that the results depended on pre-stored categorical knowledge and to assess the role of a purely perceptual property such as colour. Novel objects were used respectively in Experiment 2 and Experiment 3. Participants experienced objects in different modalities of interaction: Vision, Vision+Action, Action, and Mirror (they observed an experimenter touching and lifting them), then they were submitted to a similarity evaluation task and to a more action-based sorting task. Objects varied in intrinsic properties which had a different degree of interactivity: Grip, Shape, Size and Colour. Overall Grip, the most interactive property, was relevant for categorization, together with Size in Experiment 1 and with Shape in Experiment 2 and Experiment 3. The relevance of Grip in the sorting task confirms that goal-relevant properties are more weighted. The absence of a modality effect is discussed in the framework of the theories arguing that the vision of objects and of conspecifics interacting with objects automatically activates motor information.

**Introduction**

We typically react to objects with a motor response. For example, when we see a suitcase with a handle we tend to grasp it. Do our concepts of objects keep track of the way in which we typically interact with objects? When we categorize objects, do we use a criterion based on their perceptual properties independently of the motor responses they elicit or do we take into account properties relevant for interacting with them?

Some theorists have proposed that knowledge about objects is grounded in sensorimotor interactions between individuals and environment (e.g., Wilson, 2002). Objects are embedded in a dynamic world and are used in a dynamic way. Therefore, not only static configurational attributes but also the way objects move and the actions individuals perform with them determine objects' identity (Shepard, 1988; Viviani, 1990; Viviani & Stucchi, 1992). Against the standard cognitive view according to which perception and action are conceived of as separate and sequential processes, the recent Theory of Event Coding (TEC) proposes, for example, that perception, attention, intention and action are coded in a common representational map (Hommel, Müsseler, Aschersleben & Prinz, 2001). Accordingly, perceiving a stimulus and planning an action are not different processes operating on separate codes, as the process of perception implies active acquisition of information relevant for acting, and action planning necessarily implies and produces perceptual information. Thus, according to TEC the contents of perception and action are commensurable as they both represent events in the environment. They cannot, therefore, be conceived of as separate and sequential processes. Rather, each one influences the other in a reciprocal fashion. Experimental and brain imaging evidence has shown that common codes are more fully activated when an individual observes his/her own actions than when observing others' actions (e.g., Grezes, Frith, Passingham, 2004). Namely, the more similar an observed action is to the codes that govern one's own action planning, the higher the activation of these codes is. Support for shared mechanisms for action perception and action control, as those suggested by TEC theory, has also been provided by neurophysiological studies, and particularly by studies on mirror neurons (for reviews see Decety & Grèzes, 1999; Rizzolatti & Craighero, 2004). Mirror neurons are visuomotor neurons originally found in the macaque monkey's premotor cortex (area F5) (Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992). Single cell recording experiments have shown that these mirror neurons fire both when the monkey performs an action or when it observes another monkey or an experimenter performing a goal-directed action, such as, for example, grasping an object. In order to discharge, these neurons require an interaction between a biological effector (hand, mouth) and an object. Neurophysiological and brain imaging studies have recently provided evidence of the existence of mirror neurons in humans as well. More specifically, recent studies suggest that the homologue of the F5 area in humans is Broca's area (Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese, Seitz, Zilles, Rizzolatti, & Freund, 2001). An important difference between monkey and human mirror neurons is that, as TMS studies have shown, the latter are also active during observation of intransitive movements and not only when an action with an object is performed (Fadiga, Fogassi, Pavesi & Rizzolatti, 1995).

Importantly, the mirror neurons system may represent the neural basis for the TEC theory. As stated by Hommel *et al.* (2001), the mirror neurons findings obtained with single cell recordings "point to populations of neurons which seem to fulfil both perceptual and action-planning functions and could be considered as a neuroanatomical substrate of the common codes assumed. Yet, localizing those modules is only one step toward finding a common-coding implementation in the brain; it is also important to identify mechanisms that integrate perceptual and action-related brain activity." (Hommel *et al.*, 2001, pp. 865).

In the field of categorization, some theoretical proposals suggest that concepts are patterns of potential action (Glenberg, 1997), that is, they keep track of our sensorimotor experience with objects in order to facilitate interaction with them (Barsalou, 1999; Barsalou, Simmons, Barbey, & Wilson, 2003; Pecher & Zwaan, 2005). This view is supported by recent neural and behavioural evidence which suggests that the representation of visual objects includes motoric aspects (for a review see Borghi, 2005). On the neural side, evidence on cortical object representation has shown that tools and manipulable objects, but not non-manipulable man-made objects, activate motor-related areas (Chao & Martin, 2000; Gerlach, Law, & Paulson, 2002; Grafton, Fadiga, Arbib, & Rizzolatti, 1997). On the behavioral side, many studies have shown that under some circumstances the vision of objects elicits a simulation (Gallese & Goldman, 1998) of the possible actions to perform with them. For example, Ellis and Tucker (2000) and Tucker and Ellis (2001) demonstrated that seeing objects activates an action simulation with them. They presented participants with real objects of different size which were located behind a screen. Participants were asked to categorize the objects as natural or artefact using either a power grip or a precision grip. They found a compatibility effect between the kind of grip and a task-irrelevant dimension, the object's size. The effect was also generated when the object was located outside the reaching space, which suggests that seeing the object activates the simulation of a specific component of grasping. Moreover, the effect is maintained also when attending to an object not presented on its own but in an array of four objects (Derbyshire, Ellis, & Tucker, 2006).

In the present research we used a sorting and a similarity rating task in order to verify whether the way we interact with objects influences their categorization, and whether the properties defining objects have a different weight depending on the goal defined by the task, as predicted by TEC. In three experiments participants experienced common objects and novel objects in different modalities of interaction. Depending on the group to which they were assigned they were asked to observe the objects (Vision), to touch and move them (Action, only in Experiment 2), to observe, touch and move them (Vision+Action), or to observe the experimenter touching and moving the objects (Mirror). We introduced the Vision condition with the aim of testing whether visually experienced objects evoke motor information, as suggested by Tucker and Ellis (1998). The Mirror condition was introduced to verify whether the vision of somebody else acting with objects produces behavioural results similar to seeing objects and acting in first person.

After the learning phase, participants were asked to perform two different tasks: to sort objects by physically grouping them and to provide similarity ratings of all pairs of objects. The first task involved a fundamental motoric component, whereas the similarity assessment was probably more semantically-based. In this way we could test whether categorization was influenced by the goal for which objects are used, that is by the kind of task, as predicted by TEC.

In Experiment 1 participants were presented with everyday objects such as glasses and cups varying in shape, size and kind of handle. In Experiment 2 we used novel objects which resembled boxes, varying on the basis of properties such as size, shape, and kind of handle. We decided to manipulate only objects intrinsic properties, that is invariant object properties, such as shape and size, and not extrinsic properties, such as orientation, that may vary depending on the current context. These properties were selected on the basis of their different degree of influence on the interaction with objects (from now on “interactivity”). Among the properties, Grip was the most interactive one: some objects had handles and could be lifted, others had broken handles or no handle. Size and shape are intrinsic properties which may include both visual and motor aspects (Jeannerod, 1994; Smith, 2005). For example, recent evidence shows that, compared to colour-related words, shape-related words elicited stronger frontal activation, due to the linkage characterizing shape between visual and action information (del Prado Martìn, Hauk & Pulvermüller, 2006). In Experiment 1, performed with everyday objects, Size had more influence than Shape on the way to manipulate objects; in Experiment 2 we built novel objects in such a way that Shape could influence interaction with them, whereas Size did it only marginally. In Experiment 3 we used novel objects that also varied on the basis of a purely perceptual property: colour (red and blue). This could allow us to clarify whether categorization is preferably based on perceptual non motor properties (colour) or perceptual motor properties (shape and handle). Further details are provided while describing the experiments.

The experiments aim to test hypotheses derived from an action-based theory of concepts. If objects’ categorization is based not only on visual and geometric features but also on the kinds of action that objects afford, then interactive properties should acquire a certain relevance. However, we predict that the relevance of properties is modulated by the way of interacting with objects, and by the task participants are asked to perform with them.

As regards the influence of the way of interacting with objects, two predictions are possible. The first is that interactive properties should be more relevant when a specific action is involved in the way we experience objects. However, if the vision of objects and the vision of others acting with objects activate motor imagery (Decety, 1996; Jeannerod & Frak, 1999), that is a simulation of the possible actions to perform with objects, then the pattern of results obtained in the Vision and the Mirror conditions should not differ from that of the results obtained in the other conditions. Neural evidence in line with this hypothesis indicates that in monkeys neurons in area F5 discharge even when acting with the object is not required by the task. Similarly, in humans, tools or graspable objects activate the premotor cortex even when no response is required (Fadiga, Fogassi, Gallese, & Rizzolatti, 2000).

As to the influence of the goal on the relevance of object properties, in accordance with TEC we expect a difference in the properties' weight between the sorting and the similarity rating task. The first task was more action-oriented. Participants were required to move objects physically and to group them into spatially distinct groups. In the second task, participants were required to verbally evaluate the similarity between pairs of objects. We predict that in the sorting task, interactive properties are more relevant than in the other task, which activates more explicit and perceptual knowledge about objects. Clearly, the sorting task also implies a judgement, but the perceptual evaluation is linked to a potential action (perception-for-action), whereas in the similarity judgement task the evaluation is not linked to any further action.

## EXPERIMENT 1

In Experiment 1 participants were asked to categorize everyday objects after having experienced them in 3 different ways: only by vision (Vision condition), by touch and vision

(Action+Vision condition), and by observing the experimenter touching and lifting objects (Mirror condition). The objects consisted of 4 cups and 4 glasses varying in Shape (with straight vs. oblique edges), Size (large vs. small), and Grip (with vs. without handle). Participants were asked to evaluate the similarity between each pair of objects and to sort them into groups. They were not restricted in the number of sorting groups they could create. If objects are conceived of as patterns of potential action, interactive properties should be more relevant than perceptual properties overall. However, in accordance with TEC, we predict that the weight of the properties is modulated by the actor's goal determined by the task. More specifically, we expect that the most interactive property, Grip, is relevant in both the similarity and the sorting tasks, but particularly in the latter as it requires a motor interaction with objects. As to the experiential modality, if motor imagery is activated by seeing objects and by seeing conspecifics interacting with objects, then the pattern of results obtained in the Vision and in the Mirror condition should not differ from the results obtained in the Vision+Action condition.

## Method

### *Participants*

Thirty-three students of the University of Caserta were randomly assigned to one of the three conditions. They were 18 females and 13 males whose age ranged from 19 to 30 years (mean= 23.48, SD= 2.69). They all volunteered to take part in the experiment.

### *Materials*

Materials consisted of 8 plastic objects (4 glasses and 4 cups) varying in Shape (4 had straight and 4 oblique edges), in Size (4 small and 4 large), and in the kind of Grip (4 with a handle and 4 without). Small objects were about 5 cm tall and had a diameter of about 3 cm; large objects were about 9 cm tall and had a diameter of about 4 cm. They all were white-painted and did not differ in weight. The objects are shown in Figure 1.

Figure 1 about here

*Procedure*

All objects were placed on a table, in a random order, 10 cm distant one from another in such a way that they all were easily and completely visible. The experiment consisted of two sessions – a learning and a testing phase. Participants were randomly assigned to one of 3 conditions: Vision, Vision+Action and Mirror. Depending on the condition, during the learning phase, participants could explore the objects, which were laid on a table, according to 3 different modalities of interaction. In the Vision condition participants were asked to observe the objects without touching them. In the Vision+Action condition they had to observe, touch and lift the objects moving them to another table. In the Mirror condition they were required to observe the experimenter touching and lifting the objects. Participants were instructed to explore objects accurately, because later they should have sorted objects and rated their similarity. The exploration had no time limit. The testing phase consisted of a similarity and a sorting task. The order of presentation of the two tasks was counterbalanced among participants. During the sorting task participants were requested to sort the objects into as many groups as they wanted. They were instructed to physically sort them, i.e. to group them into spatially distinct groups on a table. During the similarity rating task, the experimenter presented participants with all pairs of objects, two each time, and asked them to verbally rate their similarity on a 7-point scale (from 1 = not similar, to 7 = very similar). The experiment was followed by an informal post-interview in which participants explained the criteria used in both the sorting and the similarity tasks.

## Statistical analyses and Results

*Statistical analyses*

As dependent variables we had similarity ratings on the 7-point scale, sorting categories and the number of sorting groups created. Sorting categories were based on the kind of property participants had chosen to group objects, that is Shape, Grip and Size. Each criterion was given 1 when chosen, and 0 when not.

In the analysis of similarity ratings, we separated the responses given to each pair of objects according to the kind and the number of shared dimensions, more specifically: none, Grip, Size, Shape, Grip+Size, Grip+Shape, Size+Shape. Two objects were considered as having in common the property “Grip” if both had a handle or if both had no handle. Therefore, 7 groups of data were obtained and for each one the mean values were computed in order to compare the similarity ratings by ANOVA models. After controlling for the assumptions of normality, homogeneity of variance-covariance matrices, linearity and multicollinearity, data were submitted to a mixed two-way ANOVA 3×7 using as between subjects factor the experimental conditions (Vision, Mirror, and Vision+Action), and as within subjects factor the 7 groups defined by the number and the kinds of shared properties. The Bonferroni test was used to analyse post-hoc effects. Besides, a non parametric test, the Friedman’s test (Friedman, 1937; 1940), was also applied to the data to further check the consistency of the results.

Further, separate analyses were carried out to explore the influence of the kind of Grip on the similarity ratings. For this reason, all pairs of object sharing the handle were compared with all pairs of objects having no handle. To do this, all the pairs sharing the property “Grip” were selected from the 7 previously defined groups. These pairs corresponded to Grip, Grip+Shape and Grip+Size. For each group, the pairs of objects having a handle were compared with the pairs of objects having no handle. Three ANOVAs 3×2 using as between subjects factor the 3 experimental conditions (Vision, Mirror, and Vision+Action) and as within subjects factor the 2 kinds of grip (handle *vs.* no handle) were carried out. All these comparisons were Bonferroni-corrected.

As regards the sorting task, we carried out a mixed two-way ANCOVA 3×3 using as between subjects factor the 3 experimental conditions (Vision, Mirror, and Vision+Action), as within subjects factor the number of times that each property (Shape, Grip, Size) was used in the sorting task, and as covariate the number of groups created. The Bonferroni test was used to analyse post-hoc effects. Besides, we also used the non parametric Friedman's test (Friedman, 1937; 1940) to verify the results.

To see whether the way of assessing the similarity between objects affected the way they were sorted, we conducted two principal component analyses and a multiple regression analysis. The factor analysis was performed on the similarity ratings and on the sorting behaviour, in order to reduce the number of variables. In the multiple regression analysis, we used as predictors the latent factors of the similarity ratings and as dependent variable the latent factor of the sorting behaviour.

*Results*

Results of evaluation of assumptions of normality, homogeneity of variance-covariance matrices, linearity, and multicollinearity were satisfactory or corrected (e.g. the Huynh-Feldt correction). The ANOVA results showed that the similarity ratings were influenced by the properties characterizing objects ($F_{(3.262,\ 97.869)} = 39.527$, $p < .001$, $\eta^2 = .57$)[1], and that neither the way of interacting ($F_{(2,\ 30)} < 1$) nor the interaction between the two main factors affected the similarity ratings ($F_{(6.525,\ 97.869)} < 1$). The post hoc analyses revealed interesting effects linked to the comparisons between the pairs of objects having two properties in common. For instance, when objects had no property in common, they were obviously rated as less similar than all other objects (mean = 1.9, $p < .001$), whereas when objects shared only one property there were no significant differences. The related means were: Size = 2.6, Shape = 2.4, and Grip = 2.2. Instead, when objects shared Size and Grip (mean = 4.7) they were rated as more similar than objects sharing Shape and Size (mean = 3.5) and Shape and Grip (mean = 2.8; $p_s < .001$). This pattern of results suggests that in the assessment of similarity the most relevant property is Size, whereas Grip and Shape have a minor influence (see Figure 2). The Friedman's non-parametric test confirmed the results.

[1] Notice that the Huynh-Feldt corrected degrees of freedom were used when describing the effect of the properties and the interaction because the properties effect was deemed to have a sphericity problem (Mauchly's Test of Sphericity $\chi_{(20)} = 119.194$; $p < .001$).

Figure 2 about here

As regards the influence of the specific kind of Grip on the rated similarity between objects, the results showed that objects having a handle were judged as more similar than objects having no handle, and this was true independently of the ways of experiencing objects (no interaction effects were found, F < 1). The effect was found when objects shared no other common property ($F_{(1,30)} = 7.29$; $p = .01$, $\eta^2 = .20$) and when they shared also Shape ($F_{(1,30)} = 10.38$; $p < .01$, $\eta^2 = .26$), but not when they shared Size ($F_{(1,30)} = 1.95$; $p = .17$, $\eta^2 = .06$). This last result highlights the importance of size as an interactive property as it reduces the impact of handles on the way of grasping objects. Table 1 illustrates the overall pattern of results.

Table 1 about here

As regards the sorting task, the ANOVA showed a main effect of the properties characterizing objects ($F_{(1.635,\ 47.402)} = 38.849$, $p < .001$, $\eta^2 = .57$)[2] and of the covariate ($F_{(1,\ 29)} = 7275.9$, $p < .001$, $\eta^2 = .99$). However, neither the effects of the way of experiencing objects ($F_{(2,\ 29)} = 1.19$; $p = .32$) nor the interaction between the two factors ($F_{(3.269,\ 47.402)} < 1$) were significant. The post-hoc analyses revealed that the kind of Grip was the most used criterion in grouping objects (mean = 3.3), followed by Shape (mean = 2.91; $p < .001$), whereas Size was almost irrelevant for this purpose (mean = .03; respectively $p < .001$ and $p < .05$). The same results were obtained with the non-parametric Friedman's test.

Finally, the principal component analysis on the sorting behaviour showed that a single latent factor, which could be defined "Grip", explained the 72% of the variance. High scores on this factor indicated a preference for choosing Grip (saturation = .96) and Shape (saturation = .89), whereas low scores indicated a preference for Size (saturation = -.68).

The same analysis on the similarity ratings revealed that a solution with three latent factors explains the 93% of the variance. The first factor was based on Shape and Grip. High scores on this factor indicated high rates of similarity for pairs sharing Grip (saturation = .99), Shape (saturation = .77) or both (saturation = .95). The second factor was based on Size and Grip. High scores indicated high rates for pairs sharing Size and Grip (saturation = .99). The third factor was based on Size. In this case high scores indicated high rates of similarity for pairs sharing Size (saturation = .63) or Size and Shape (saturation = .97). Notice that the Oblimin rotation showed that the first and the third factors were correlated ($r$ = .42) while the second factor was independent of the first ($r$ = .06) and the third factor ($r$ = .02).

The multiple regression analysis with the Grip factor of the sorting task as dependent variable and the three factors of the similarity task as predictors showed that the similarity ratings predicted only a small amount of variance of the sorting behaviour ($F_{(3,32)} = 7.111$, $p = .001$; $R^2 = .36$). If participants rated as more similar objects sharing the Shape-Grip, in the sorting task they chose more often Shape and Grip (*beta* = .35; $p$ = .035). The same happens with objects sharing Size and Grip (*beta* = .36; $p$ = .02). Finally, if they rated as more similar objects having in common Size or Shape, they used more frequently Size in the sorting task (*beta* = -.59; $p$ = .001). However, the 64% of variance of the sorting task is not explained by the similarity ratings and this confirms that the relevance of the properties of objects is tuned to a large extent by the kind of task.

**Discussion**

The results suggested that properties influencing interaction with objects, that is Grip and Size, were more relevant than Shape in both tasks. Consider that in this experiment Size was more interactive than Shape as the latter was defined exclusively on the basis of the degree of inclination of the objects' edges, that could be straight or oblique. If, as TEC assumes, stimulus objects and

[2] The Huynh-Feldt corrected degrees of freedom were used due to a sphericity problem of the properties effect (Mauchly's Test of Sphericity $\chi_{(2)} = 10.978$; $p < .01$).

event plans are coded at a distal, abstract level, then the degree of straightness of the edges should not be influent as it has scarce probability of influencing the action goal.

In addition, the results showed that depending on the goal determined by the task, different properties acquire weight, as predicted by TEC. Size was the most relevant property when assessing the similarity between objects, whereas Grip was the most important property when sorting objects into categories. Therefore, in the sorting task interactive properties were more relevant than in the similarity rating task and this effect emerged independently of the number of sorting categories created. The relevance of the goal/task is confirmed by the regression analysis showing that the results obtained in the sorting task are not explained by those obtained in the similarity task. Briefly, then, the importance of interactive properties increased as much as the task at hand involved spatial and motor components.

The absence of an effect of experiential modality might be explained by the fact that seeing objects or seeing somebody else interacting with an object, activates a simulation of the action, as if a real interaction with the object were occurring. An alternative explanation is also possible. It could be that the goal defined by the task overrides the importance of the experiential modality.

## EXPERIMENT 2

Experiment 1 showed that the criteria chosen to categorize objects are based on both visual and dynamic interactive properties, such as Size and Grip. However, one could except that the presence of objects of two different categories may have influenced the results. The distinction between kind of Grip, due to the presence or absence of a handle, reflected also the distinction between two categories of everyday objects, cups (with handle) and glasses (without handles). In addition, the difference in Size between large and small objects may depend on accessing information on different subordinate categories, that is coffee vs. tea cups and liqueur vs. wine glasses. Experiment 2 was designed in order to replicate Experiment 1 by controlling for possible sources of artefacts. In order to avoid possible confounds, we built 16 novel objects similar to paper boxes that varied in Shape, Size and kind of Grip (with handle or without). Because they were novel, the objects did not belong to any pre-specified category. Compared to Experiment 1, we varied the degree of "interactivity" of the different object properties. Similarly to Experiment 1, the property Grip was clearly the most interactive one: some objects had handles and could be lifted, whereas other objects had broken handles or no handles. The boxes were built in such a way that lifting them without using the handle was possible, but, especially with squared shapes, it was not easy because participants had to unnaturally extend their hands. Differently from Experiment 1, however, Shape was more interactive than Size. Objects Shape varied as there were either triangles or squares, and this could clearly influence the way to manipulate and lift them, in case they could not be grasped with the handles. As far as Size is concerned, differently from Experiment 1, the amount of variation in size was not enough to influence the interaction with objects. In fact, all objects were manipulable ones and, if they could not be grasped using the handles, they all elicited a power grip. As in Experiment 1, Size did not influence liftability, because all objects were of comparable weight. Thus, in this experiment Grip was the most interactive property, followed first by Shape and then by Size. Compared to Experiment 1, two further procedure modifications were made. First, in order to better control the sorting task, we forced participants to sort objects into groups composed of the same number of objects. Second, we introduced a further exploratory condition, the Action condition, in which participants had to manually explore and lift the objects without seeing them.

**Method**

*Participants*

Thirty-two students of the University of Bologna were randomly assigned to one of four conditions. They were 12 males and 20 females whose age ranged from 19 to 32 (mean=23.97, SD= 3.59). They all took part in the experiment on a voluntary basis.

*Materials*

Materials consisted of 16 boxes varying in Shape (8 squared and 8 triangular), in Size (8 small and 8 large), in kind of Grip (8 with a handle and 8 with no handle), as illustrated in Figure 3. As regards objects with a handle, there were 4 round-shaped handles and 4 square-shaped handles. As regards objects with no handle, 4 boxes had square-shaped broken handles and 4 boxes had a short ribbon which could be pinched instead of a proper handle. The boxes did not vary in weight.

Figure 3 about here

*Procedure*

The experiment consisted of two sessions: a learning and a testing phase. Participants were randomly assigned to one of 4 conditions. Depending on the condition, during the learning phase participants could explore the objects, which were laying on a table, according to 4 different modalities of interaction. In the Vision condition participants were asked to observe the boxes without touching them. In the Vision+Action condition they had to observe, touch and lift the boxes. In the Action condition they were required to touch and lift the boxes while being blindfolded. In the Mirror condition they had to observe the experimenter touching and lifting the boxes. The exploration had no time limit.

During the testing phase, participants had to sort the objects into two groups composed of four objects each. They were instructed to physically sort them, i.e. to group them into two spatially distinct groups on a table. Participants were firstly asked to explore 8 objects and then to sort them. In a second session, they had to do the same with the remaining 8 objects. The order of presentations of the two groups of objects was counterbalanced. Afterwards, the experimenter presented participants with all pairs of objects, two each time, and asked participants to verbally rate their similarity on a 7-point scale (from 1 = not similar, to 7 = very similar).

The experiment was followed by an informal post-interview in which participants explained the criteria used in both the sorting and the similarity tasks.

## Statistical analyses and Results

### *Statistical analyses*

As dependent variables we had similarity ratings on the 7-point scale and sorting categories. As in the first experiment, sorting categories (Shape, Grip, Size) were given 1 when used to create a group, and 0 when not.

In the analysis of similarity ratings, we separated the responses given to each pair of objects according to the kind and the number of shared properties, and this gave rise to 8 groups: none, Shape, Grip, Size, Shape+Grip, Shape+Size, Grip+Size, Shape+Grip+Size. After controlling for the assumptions of normality, homogeneity of variance-covariance matrices, linearity and multicollinearity, data were submitted to a mixed two-way ANOVA 4×8 using as between subjects factor the experimental conditions (Vision, Vision+Action, Action and Mirror) and as within subjects factor the 8 groups of data. The Bonferroni test was used to analyze post-hoc effects. Besides, as for Experiment 1, the non parametric Friedman's test (Friedman, 1937; 1940) was applied to verify the results.

Similarly to Experiment 1, separate analyses were carried out to explore the influence of the specific kind of Grip on the similarity ratings. Four ANOVAs 4×2 using as between subjects factor the 4 experimental conditions (Vision, Mirror, and Vision+Action) and as within subjects factor the 2 kinds of Grip (handle *vs.* no handle) were carried out on the pairs sharing only: Grip, Grip+Shape, Grip+Size, Shape+Grip+Size. All these comparisons were Bonferroni-corrected.

In order to evaluate the role of the shape of the handle on the similarity ratings, the mean similarity of groups with Grip of the same shape (e.g. circular-circular or squared-squared) were compared to the mean similarity of groups with Grip of different shape (e.g. circular-squared or squared-circular). Specifically, three ANOVAs 4×2 using as between subjects factor the 4 experimental conditions (Vision, Vision+Action, Action and Mirror) and as within subjects factor the 2 types of Grip (same shape of the handle *vs.* different shape of the handle) were carried out on the pairs sharing only: Grip, Grip+Shape, Grip+Size.

As regards the sorting task, we carried out a mixed two-way ANOVA 4×3 using as between subjects factor the experimental conditions (Vision, Vision+Action, Action and Mirror) and as within subjects factor the number of times that a property (Shape, Grip and Size) was used. The Bonferroni test was used to analyse post-hoc effects. Similar to Experiment 1, the data were also analyzed with the Friedman's test (Friedman, 1937; 1940).

Also in this case, we conducted two principal component analyses and a multiple regression analysis in order to verify the relation between the sorting and the similarity rating tasks.

*Results*

Results of evaluation of assumptions of normality, homogeneity of variance-covariance matrices, linearity, and multicollinearity were satisfactory or corrected. The ANOVA showed that the similarity ratings were strongly influenced by the properties characterizing objects ($F_{(3.518, 94.994)} = 152.906$, $p < .001$, $\eta^2 = .85$)[3]; instead, the way of interacting with them had only a marginal effect ($F_{(3, 27)} = 3.033$, $p = .046$, $\eta^2 = .25$), and there was no interaction between the two factors ($F_{(10.555, 94.994)} = 1.544$, $p = .132$, $\eta^2 = .15$). The post hoc analyses for the within effect showed that when objects shared no property they were assessed as less similar than all other objects (mean = 1.6), and when they shared Shape, Size and Grip they were assessed as more similar than all others (mean = 5.7). Apart from this obvious result, the comparisons between the pairs of objects sharing one property or two properties are more informative. Objects were evaluated more similar when they shared Shape (mean = 3.6) than Size (mean = 2.6) and Grip (mean = 2.2; all $p_s < .001$). Further, the similarity ratings were significantly higher for objects sharing Shape and Size (mean =

[3] The Huynh-Feldt corrected degrees of freedom were used due to a sphericity problem of the properties effect (Mauchly's Test of Sphericity $\chi_{(27)} = 171.34$; $p < .001$).

5.1) than Shape and Grip (mean = 4.2), and Size and Grip (mean = 3.2; all $p_s < .001$). There was also a significant difference between the last two factors ($p < .001$). This pattern of results suggests that in the assessment of similarity the most relevant property is Shape, whereas Grip and Size have only a marginal importance (see Figure 4). Finally, the post-hoc analyses for the between effect showed no significant results. As for Experiment 1, the non-parametric Friedman's test confirmed all the results.

Figure 4 about here

As regards the influence of the specific kind of Grip, the ANOVAs showed that this interactive property significantly affected the estimated similarity between objects, and this influence was independent of the way objects had been previously experienced (no interactive effect were found, in all cases with $p > .05$). Objects having a handle were judged as more similar than objects having no handle (see Table 2 for the mean values) when they shared no other property ($F_{(1,28)} = 4.401$; $p < .05$, $\eta^2 = .14$), when they shared only Shape ($F_{(1,28)} = 21.01$; $p > .001$, $\eta^2 = .43$), and when they shared both Shape and Size ($F_{(1,28)} = 36.57$; $p < .001$, $\eta^2 = .57$). However, the importance of the kind of Grip dropped when objects shared only Size ($F_{(1,28)} = .523$; $p = .48$, $\eta^2 = .02$), probably because – as discussed below – in this case they could be lifted in uniform ways.

Table 2 about here

As regards the shape of the handle, the ANOVAs showed that this property significantly affected the estimated similarity between objects and this influence was independent of the way objects had been previously experienced (no interactive effect were found, in all cases with $p > .05$). Objects having the same shape of handle were judged as more similar than objects having handles with different shapes when they shared only Grip ($F_{(1,28)} = 20.539$; $p < .001$, $\eta^2 = .42$), when they shared both Grip and Shape ($F_{(1,28)} = 30.34$; $p < .001$, $\eta^2 = .52$), and when they shared both Shape and Size ($F_{(1,28)} = 11.01$; $p < .01$, $\eta^2 = .28$) (see Table 3 for the mean values).

Table 3 about here

As regards the sorting task, the ANOVA showed a main effect of the properties ($F_{(1.735, 48.574)} = 13.968$, $p < .001$, $\eta^2 = .33$), but neither effect of the way of experiencing objects ($F_{(3, 28)} < 1$) nor interaction ($F_{(5.204, 48.574)} = 1.287$, $p = .298$, $\eta^2 = .12$)[4]. The post-hoc analysis revealed that Shape (mean = 1.2) and Grip (mean = .7) were chosen more often than Size (mean = .1; all $p_s < .01$) to sort objects. Results were confirmed with the Friedman's test.

Finally, the principal component analysis on the sorting behaviour showed that a single latent factor, which could be defined "Grip", explains the 62% of the variance. High scores on this factor indicate a preference for choosing Grip (saturation = .92), whereas low scores a preference for using Shape (saturation = -.99). Notice that Size was eliminated because it was rarely used.

The same analysis on the similarity ratings revealed that two latent factors explained the 79% of the variance. The first factor was based on Shape. High scores on this factor indicated high ratings of similarity for objects sharing Shape (saturation = .99), Shape+Grip (saturation = .84), Shape+Size (saturation = .84). The second factor was based on Size and Grip. In this case high scores indicated high ratings of similarity for objects sharing Size+Grip (saturation = .99), Size (saturation = .80) or Grip (saturation = .82). Notice that the Oblimin rotation showed that the two factors were positively correlated: $r = .42$.

The multiple regression analysis with the Grip factor of the sorting task as dependent variable and the Shape and the Size-Grip factors of the similarity task as predictors, showed that the similarity ratings predicted only a small amount of variance of the sorting behaviour ($F_{(2, 28)}$ =

[4] The Huynh-Feldt corrected degrees of freedom were used due to a sphericity problem of the properties effect (Mauchly's Test of Sphericity $\chi_{(2)} = 10.978$; $p < .01$).

3.456, *p* = .046; $R^2$ = .14). Within this small amount, if participants rated as more similar objects sharing Shape, in the sorting task they chose this property more than Grip (*beta* = -.43; *p* =.027). If they rated as more similar objects with common Size or Grip, in the sorting task they used Grip more than Shape (*beta* = .39; *p* =.046). However, the 86% of variance of the sorting task was not explained by the similarity ratings, and this confirms that the two tasks activated in a selective way the properties of objects. More specifically, Shape was the most important property when assessing the similarity, whereas both Shape and Grip were relevant when physically grouping objects.

**Discussion**

The results confirm with novel objects what was found in Experiment 1 with everyday objects: interactive properties were the most relevant for object categorization. In this experiment Size had less weight than the other properties across tasks, probably because, even though it was a perceptually salient property, it did not influence interaction with objects. The relevance of Grip is worth discussing as it stressed the importance of the dynamical information in categorization. When objects had a handle, they were lifted in the same way independently of the shape of the handle. Presumably, this common motoric component became a perceptual feature which increased the assessed similarity between objects. Instead, when objects had a ribbon or a broken handle, subjects tended to lift them in different ways and therefore they had no specific motoric “marker” associated with them. The fact that the specific kind of Grip did not affect the similarity ratings when objects had the same size might be interpreted by adopting the same argument. For instance, participants tended to lift small objects by pinching the ribbons or the broken handle, and to grasp large objects by extending their hand. This communality of actions concealed the motoric relevance of handles. Post-experimental interviews and observation of the participants’ behaviour, gave some support to this interpretation. However, the significant effect of the shape of the handle could lead to interpreting the Grip effect as deriving from a perceptual rather than motor factor. If this were true, we should not have had the Grip effect itself, which is due to objects that could be lifted in similar ways. Experiment 3 should disentangle the role of purely perceptual properties and motoric properties in categorization.

Similarly to Experiment 1, the relevance of the different properties varied depending on the task. In the similarity rating task, Shape was more important than Size and Grip. This was true across all conditions. Instead, in the sorting task both Shape and Grip were more important than Size. This suggests that categorization was affected by the goal for which knowledge about objects is used: when the task was more semantically-based, also visual and perceptual features played a role, whereas when the task was more action-oriented, interactive properties acquired a significant relevance. As in Experiment 1, the different influence of the two tasks was confirmed by the regression analysis showing that the results obtained in the sorting task were not explained by those obtained in the similarity task. Instead, the way of experiencing objects did not strongly affect their categorization.

As proposed in the discussion of Experiment 1, a possibility is that, independently of the specific experiential modality, a multimodal object representation is created. This is confirmed by studies showing that seeing objects potentiates the affordances linked with them by re-activating previous experiences with similar objects and / or with objects of the same category (Barsalou *et al.*, 2003; Pecher & Zwaan, 2005; Chao, & Martin, 2000; Gerlach *et al.*, 2002; Tucker & Ellis 2001). This would explain the absence of a difference between the Vision, the Mirror and the other two interactive conditions (Action and Action+Vision). Parts of this multimodal representation would be activated depending on the action goal defined by the task. Therefore, the experiential modality would be overwhelmed by the goal defined by the task.

## EXPERIMENT 3

Experiment 1 showed that the criteria chosen to categorize objects are based on both visual properties and dynamic interactive properties, such as handle and size. Experiment 2 was a control experiment with novel objects that confirmed the importance of the dynamic interactive properties. In Experiment 3 we aimed to test what would happen if participants were asked to sort objects and to evaluate their similarity when these objects also varied on the basis of a purely perceptual property: Colour. Thus, in this experiment three object properties were manipulated: Colour (only visual), Shape (visual and motor), Handle (interactive); and we considered three ways of experiencing objects: only by vision, by vision and touch, and by observing the experimenter touching and lifting objects. The Action condition was eliminated given the visual relevance of Colour.

If object vision activates motor information, participants should still sort objects on the basis of Shape and Handle, even if the differences in Colour were particularly salient. Further, Shape and Colour should be the preferred dimensions in assessing the similarity between objects. However, it is possible that the relevance of Colour emerges when objects are explored in a purely visual way.

## Method

*Participants*

Twenty-one students of the University of Bologna were randomly assigned to one of the three conditions. They were 9 males and 12 females whose age ranged from 19 to 32 (mean=24.24, SD= 3.43). They all took part in the experiment on a voluntary basis.

*Materials*

Materials consisted of the 8 large boxes used in Experiment 2 with the difference that half were completely covered with blue and half with red paper. Specifically, the 8 large boxes varied in Shape (4 squared and 4 triangular), in kind of Handle (4 liftable and 4 not liftable) and in Colour (4 blue and 4 red).

*Procedure*

The procedure was the same as in Experiment 1 and Experiment 2 with the exception that there was only one sorting session.

## Statistical analysis and Results

*Statistical analyses*

The criteria followed for the statistical analyses were the same as in previous experiments.

In the analysis of similarity ratings, we separated the responses given to each pair of objects according to the kind and the number of shared properties, and this gave rise to 7 groups: none, Shape, Handle, Colour, Shape+Handle, Shape+Colour, Handle+Colour. After controlling for the assumptions of normality, homogeneity of variance-covariance matrices, linearity and multicollinearity, data were submitted to a mixed two-way ANOVA 3×7 using as between subjects factor the experimental conditions (Vision, Vision+Touch, Mirror) and as within subjects factor the mean ratings of similarity to the 7 different groups. The Bonferroni test was used to analyse post-hoc effects. Besides, the non parametric Friedman's test (Friedman, 1937; 1940) was also applied.

Similarly to previous experiments, three ANOVAs 3×2 using as between subjects factor the 3 experimental conditions and as within subjects factor the 2 kinds of Grip (handle *vs.* no handle) were performed. All the comparisons were Bonferroni-corrected.

As regards the sorting task, given that in this experiment participants were asked to perform the classification in one session and that they could generate only two groups, there was not enough variance to carry out an ANOVA. Therefore, we decided to use a one-way chi-square analysis to compare the frequency of choice of each feature and a 3×3 chi square analysis to see whether the criterion chosen was influenced by the three experimental conditions. The standardized residuals were used to analyse post-hoc effects.

To explore the possible influence of the way of evaluating the similarity between objects on the way they are sorted, we conducted a discriminant function analysis. We used as predictors the latent factors of the similarity ratings and as dependent variable the property chosen in the sorting behaviour.

*Results*

Results of evaluation of assumptions of normality, homogeneity of variance-covariance matrices, linearity, and multicollinearity were satisfactory or corrected. The ANOVA results showed that the similarity ratings were strongly influenced by the properties characterizing objects ($F_{(3.410,\ 61.372)} = 37.618$, $p < .001$, $\eta^2 = .68$)[5]. However, there were neither main effect of the three experimental conditions ($F_{(2,18)} < 1$) nor interaction between the two factors ($F_{(6.819,\ 61.372)} < 1$). In line with previous experiments, the post hoc analyses for the within effect confirm the importance of Shape in this semantically-biased task. More specifically, objects were obviously estimated as less similar than all other objects pairs when they had no common property (mean = 1.8, all $p_s < .001$). When they had one common property, they were evaluated as more similar when the common property was Shape (mean = 4.1) rather than Colour (mean = 3.3; $p = .009$) and Grip (mean = 2.8; $p = .002$). There was also a significant difference between the last two properties ($p < .05$). When objects shared Shape and Grip (mean = 5.3) or Shape and Colour (mean = 4.9) they were evaluated as more similar than objects sharing Grip and Colour (mean = 3.98; respectively $p < .001$, and $p < .05$). The data were also analyzed by means of the non-parametric Friedman’s test. All the results were confirmed. Therefore, in the assessment of similarity the most relevant property is the Shape, whereas Colour and Grip are much less important (see figure 5).

Figure 5 about here

As regards the influence of the ways of grasping, the ANOVA showed that objects having a handle were rated as more similar than objects having no handle (see Table 4 for the mean values) when they shared no other property ($F_{(1,18)} = 5.575$; $p < .05$, $\eta^2 = .24$), while there was no significant difference when they shared Shape ($F_{(1,18)} < 1$) or Colour ($F_{(1,18)} < 1$).

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[5] Note that the Huynh-Feldt corrected degrees of freedom were used when describing the effect of the properties and the interaction because the properties effect was deemed to have a sphericity problem (Mauchly's Test of Sphericity $\chi_{(20)} = 55.384$; $p < .001$).

Table 4 about here

As regards the sorting task, the Chi-square showed a tendency to prevail of Grip (58%) on Colour (26%) and Shape (16%) that approached statistical significance ($\chi_{(2)}$ = 5.474; $p$ = .06). Further, there was no interaction between the three experimental conditions and the properties chosen ($\chi_{(4)}$ = 5.884; $p$ = .208; see Table 5).

Table 5 about here

Finally, the discriminant analysis on the sorting behaviour in which we used the property chosen as dependent variable (Shape, Grip or Colour) and the similarity ratings on the six pairs sharing at least one feature as predictors (Shape, Grip, Colour, Shape+Grip, Shape+Colour, and Grip+Colour), showed that the similarity rating do not predict the sorting task ($\Lambda_{1\text{-}2(12)}$ = .499; $p$ = .670; $\Lambda_{2\text{-}3(5)}$ = .797; $p$ = .690).

**Discussion**

The results of Experiment 3 confirm that Shape is the preferred property when assessing the similarity between objects, whereas the way of grasping is dominant when sorting objects into categories. In both cases this preference seems independent of the way of exploring objects. Therefore, in the sorting task interactive properties are more relevant than in the similarity rating task. Interestingly, in this last task – which should be more based on objects' visual properties – Colour is not important. This is even more surprising if we consider that vision was involved in each explorative modality. In short, then, interactive properties such as Shape and Grip prevail on a purely visual one (Colour), and the importance of the interactivity increases to the extent that the task participants are asked to do involves motor components.

**Conclusion**

The experiments support the view according to which object categorization is grounded on sensorimotor experience and is aimed at action (Gallese, & Lakoff, 2005). In all experiments the most interactive property, Grip, emerged as an important property for categorization, particularly in the sorting task. Besides Grip, the most important property in Experiment 1 was object Size, in Experiment 2 and Experiment 3, it was object Shape. Thus the two most interactive properties (Grip and Size in Experiment 1, Grip and Shape in Experiment 2 and Experiment 3) were always the most relevant across the three experiments and the two tasks. Let us clarify why in Experiment 1 Size was the most interactive property, whereas in Experiment 2 and Experiment 3 Shape was more interactive than Size. This was due to the fact that, in Experiment 1, Shape variations were visually evident but influenced only in a limited way the interaction with objects. Namely, as it can be seen in Figure 1, shape variations were restricted to the differences between object edges, which could be either straight or oblique. These variations do not substantially influence the kind of grip required to grasp the object and lift it, even if they might have some influence on finger extension. Whereas the differences in Shape were not consistent, in Experiment 1 the differences in Size largely influenced the kind of grip required to grasp the object. Namely, small objects were 5 cm tall and with a diameter of 3 cm, whereas large objects were 9 cm tall and had a diameter of 4 cm. Differently from Experiment 1, in Experiment 2 and Experiment 3 Shape variations strongly influenced potential interaction with objects. Namely, we presented objects that were either squares or triangles, and this difference in shape had a strong impact on the potential interaction with objects. On the contrary, differences in Size had no strong influence, even if it might have an effect on the degree of finger extension. One could except that preference for Shape relies on semantic or perceptual factors. However, if participants had grouped objects based on these factors, they should have used the presence/absence of a handle as a criterion, therefore they would have included objects with a broken handle within the “handle present” group. But this is not what participants did in our experiments. For all these reasons, Size can be conceived of as more interactive than Shape in Experiment 1, whereas in Experiment 2 and Experiment 3 Shape was more interactive than Size.

Interestingly, the way we keep information on objects depends also on what we currently have to do with them, on our intentions and action plans. The different salience acquired by Grip in the two tasks is probably due to the fact that the sorting task was action-oriented, while in the rating task, participants had to analyze the different object properties in order to produce the evaluations. Our results clearly confirm TEC (Hommel *et al.*, 2001), as they show that goal-related features of objects and action plans are weighted more strongly than other features. When we have to perform an action-based task, such as a spatial sorting task, interactive properties assume more relevance than when we have to carry out an evaluation task, as producing similarity judgements. Clearly, the sorting task implies an evaluation as well, but this evaluation is directly aimed at inter-acting with objects.

The absence of differences between experiential modalities could be due to the fact that the goal defined by the task overcomes the role played by the experiential modalities. However, an alternative explanation is viable. The absence of this effect can be explained by the activation of a simulation process triggered by the vision of an object or of a person interacting with it. This simulation process would lead to the activation of the same motor information activated while directly experiencing the object, either through the tactile or both the tactile and the visual modality. If this intriguing possibility is true, our results would provide behavioral evidence in favor of the existence in humans of a mirror neuron system. Recent behavioural evidence converges in showing that even seeing the image of an effector followed by the image of an object, activates motor information (Borghi, Bonfiglioli, Ricciardelli, Rubichi & Nicoletti, 2007; Fisher, Prinz, & Lotz, in press).

Overall, the general pattern of results we found allows concluding that object categorization is guided by action, that is object concepts are not only based on sensorimotor experiences but are also aimed at action.

**References**

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22,* 577-609.

Barsalou, L.W., Simmons, W.K., Barbey, A.K., & Wilson, C.D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Science, 7,* 84-91.

Borghi, A.M. (2005). Object concepts and action. In D. Pecher & R. Zwaan (Eds.). *Grounding cognition. The role of perception and action in memory, language, and thought*. New York: Cambridge University Press.

Borghi, A., Bonfiglioli, C., Lugli, L., Ricciardelli, P., Rubichi, S., & Nicoletti, R. (2007). Are visual stimuli sufficient to evoke motor information? Studies with hand primes. *Neuroscience Letters, 411,* 17-21.

Buccino, G., Binkofski, F., Fink, G.R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R.J., Zilles, K., Rizzolatti, G., Freund, H.J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: an fMRI study. *European Journal of Neuroscience,* 13, 400–404.

Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *Neuroimage*, *12,* 478-484.

Decety, J. (1996). The neurophysiological basis of motor imagery. *Behavioural Brain Research, 77,* 45-52.

Decety, J., & Grèzes, J. (1999) Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Neuroscience* 3:172–78.

del Prado Martìn, F.M., Hauk, O., & Pulvermüller, F. (2006). Category specificity in the processing of color-related and form-related words: An ERP study. *Neuroimage, 29,* 29-37.

Derbyshire, N., Ellis, R., & Tucker, M. (2006). The potentiation of two components of the reach-to-grasp action during object categorization in visual memory. *Acta Psychologica*, *122,* 74-98.

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research,* 91, 176–80.

Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology, 91,* 451-471.

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology,* 73, 2608–2611.

Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (2000). Visuomotor neurons: ambiguity of the discharge or `motor` perception? *International Journal of Psychophysiology, 35*, 165-177.

Fisher, M.H., Prinz, J., & Lotz, K. (in press). Grasp cueing shows obligatory attention to action goals. *Quarterly Journal of Experimental Psychology*.

Friedman, M. (1937). The use of ranks to avoid the assumption of normality implicit in the analysis of variance. *Journal of the American Statistical Association*, *32*, 675-701.

Friedman, M. (1940). A comparison of alternative tests of significance for the problem of *m* ranking. *Annals of Mathematical Statistics*, *11*, 86-92.

Gallese, V., & Lakoff, G. (2005). The Brain’s Concepts: The Role of the Sensory-Motor System in Reason and Language. *Cognitive Neuropsychology, 22*, 455-479.

Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Science*, *12*, 493-501.

Gerlach, C., Law, I., & Paulson, O.B. (2002). When action turns into words. Activation of motor-based knowledge during categorization of manipulable objects. *Journal of Cognitive Neuroscience, 14*, 1230-1239.

Glenberg, A.M. (1997). What memory is for. *Behavioral and Brain Sciences, 20,* 1-55.

Grafton, S.T., Fadiga, L., Arbib, M.A., & Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *Neuroimage*, *6*, 231-236.

Grezes, J., Frith, C.D., & Passingham, R.E. (2004). Inferring false beliefs from the actions of oneself’s and others: an fMRI study. *Neuroimage, 21*, 744-750.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849-878.

Jeannerod, M. (1994). Object oriented action. Insights into the reach grasp movement. In K. M. B. Bennet, & U. Castiello (Eds.), *Insights into the Reach to Grasp movement* (pp. 3-15). Amsterdam: Elsevier.

Jeannerod, M., & Frak, V. (1999). Mental imaging of motor activity in humans. *Current opinion in neurobiology, 9*, 735-739.

Pecher, D., & Zwaan, R. (Eds.) (2005). *Grounding cognition. The role of perception and action in memory, language, and thought*. New York: Cambridge University Press.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, *27*, 169-92.

Shepard, R.N. (1988). The role of transformations in spatial cognition. In J. Stiles-Davis, M. Kritchevsdy & U. Bellugi (Eds.), *Spatial cognition: Brain bases and development* (pp. 81-110). Hillsdale, NJ: Lawrence Erlbaum Associates.

Smith, L. (2005). Action alters shape categories. *Cognitive Science*, *29*, 665-679.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human perception and performance, 24*, 3, 830-846.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8,* 769-800.

Viviani, P. (1990). Motor-perceptual interactions: the evolution of an idea. In M. Piattelli Palmarini (Ed.), *Cognitive Science in Europe: Issues and trends* (pp. 11-39). Ivrea: Golem.

Viviani, P., & Stucchi, N. (1992). Biological movements look uniform: evidence for motor-perceptual interactions. *Journal of Experimental Psychology. Human Perception and Performance*, *18,* 603-623.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*, 625-636.

Figure 1 – Examples of the everyday objects used in Experiment 1.

Figure 2 – Mean similarity ratings for all pairs of objects grouped by the number and the kind of common properties. Equal letters indicate equal means ($p > .05$).

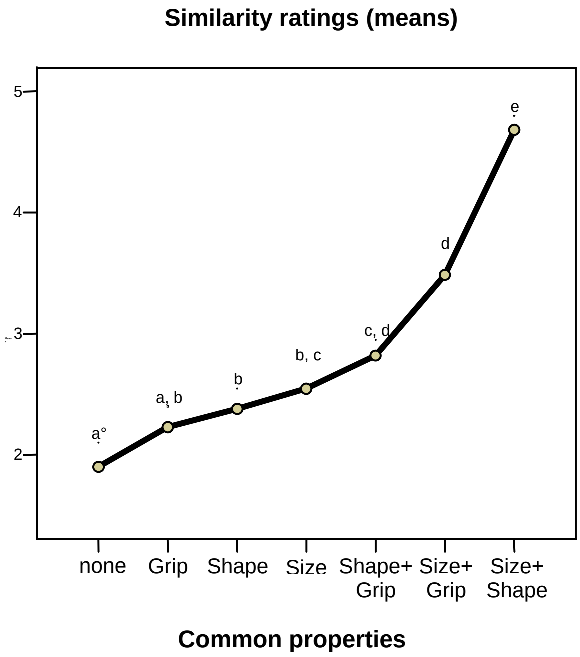

Figure 3 – Examples of the novel objects used in Experiment 2.

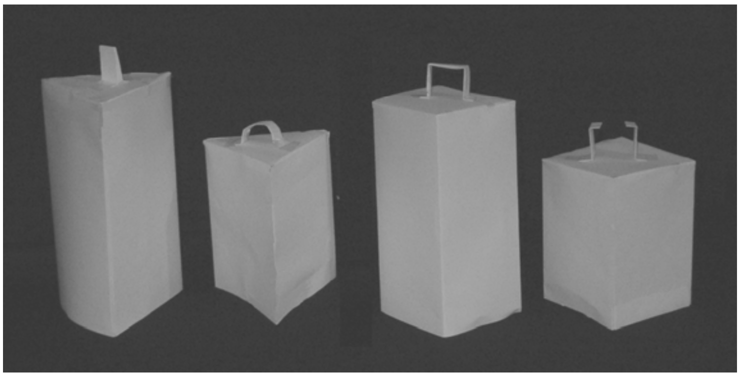

Figure 4 – Mean similarity ratings for all pairs of objects grouped by the number and the kind of common properties. Equal letters indicate equal means (*p* > .05).

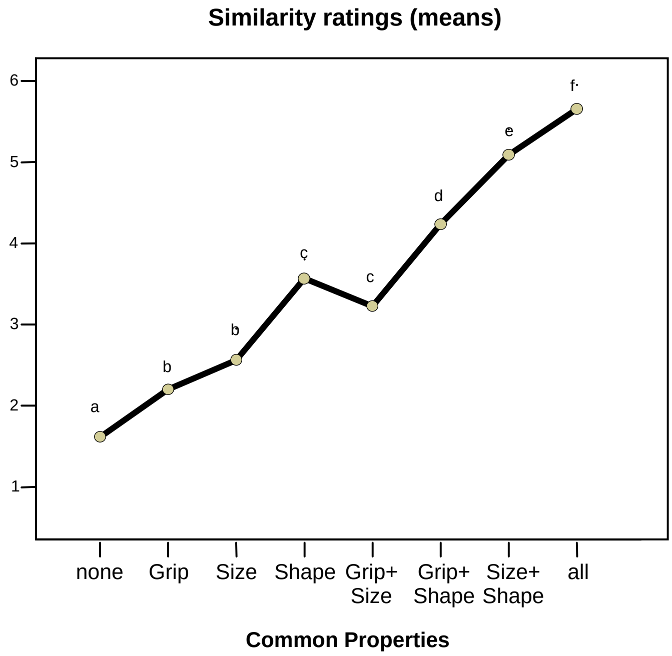

Figure 5 – Mean similarity ratings for the pairs grouped by the number and the kind of common properties. Equal letters indicate equal means (*p* > .05).

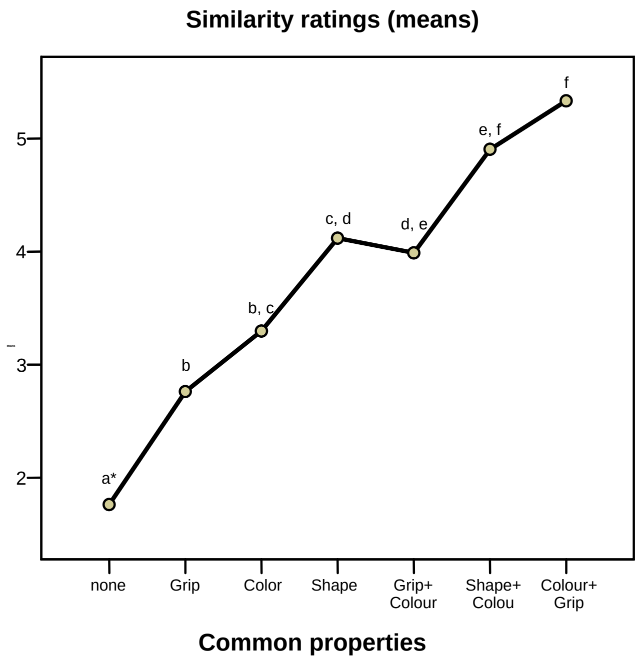

Table 1 – Mean similarity ratings for objects with handle and with no handle. Equal letters indicate equal means ($p > .05$).

| Common properties | Handle | No handle |
|---|---|---|
| GRIP | 2.6[a] | 1.9[b] |
| GRIP & SHAPE | 3.3[a] | 2.4[b] |
| GRIP & SIZE | 4.9[a] | 4.5[a] |

Table 2 – Mean similarity ratings for objects with handle and with no handle. Equal letters indicate equal means ($p > .05$).

| Common properties | Handle | No handle |
| --- | --- | --- |
| GRIP | $2.3^{a}$ | $2.1^{b}$ |
| GRIP & SHAPE | $4.4^{a}$ | $3.98^{b}$ |
| GRIP & SIZE | $3.3^{a}$ | $3.2^{a}$ |
| GRIP, SHAPE & SIZE | $6.02^{a}$ | $5.3^{b}$ |

Table 3 – Mean similarity ratings for objects with handle of the same shape and with handle of different shape. Equal letters indicate equal means (*p* > .05).

| Common properties | Same shape of the handle | Different shape of the handle |
|---|---|---|
| GRIP | 2.6[a] | 2[b] |
| GRIP & SHAPE | 3.6[a] | 2.9[b] |
| GRIP & SIZE | 4.7[a] | 4.2[b] |

Table 4 – Mean similarity ratings between objects with handle and with no handle for the pairs grouped by the kind of common properties. Equal letters indicate equal means ($p$ > .05).

| Common properties | Handle | No handle |
|---|---|---|
| GRIP | $3.1^{a}$ | $2.4^{b}$ |
| GRIP & SHAPE | $5.3^{a}$ | $5.3^{a}$ |
| GRIP & COLOR | $4.1^{a}$ | $3.8^{a}$ |

Table 5 – Distribution of the sorting behaviour in the three experimental conditions.

| | SORTING | | | |
|---|---|---|---|---|
| CONDITION | *Shape* | *Grip* | *Color* | Total |
| *Vision* | 1 **(17%)** | 5 **(83%)** | - | 6 **(100%)** |
| *Vision+Touch* | - | 4 **(67%)** | 2 **(33%)** | 6 **(100%)** |
| *Vision* | 2 **(29%)** | 2 **(29%)** | 3 **(42%)** | 7 **(100%)** |
| Total | 3 **(16%)** | 11 **(58%)** | 5 **(26%)** | 19 **(100%)** |