

In press on Acta Psychologica – accepted on November, 2009

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Categorization and action: What about object consistence?

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Abstract

Categorization studies have focused on the importance of a variety of perceptual properties (shape, size, weight). The present study explored whether the softness or hardness of an object might influence the way we categorize and consider category members. Of additional interest was whether information on consistence is automatically activated and whether it is modulated by the kind of task and of response modality. Three experiments demonstrated that information on consistence is automatically activated, and it helps us to distinguish between artefacts and natural objects. Interestingly, the results are in agreement with the simulation hypothesis; namely, when we consider artefacts, we simulate using them and information on their consistency is activated; this simulation is modulated by the task. The way we differently process artefacts and natural objects across the experiments confirms the simulation hypothesis and our sensitivity to the response modality.

Keywords: Categorization; Action; Object consistence; Embodied cognition; Motor simulation.

PsycINFO Classification code: 2330 Motor Processes; 2340 Cognitive Processes.

Categorization and action: What about object consistence?

Introduction

Literature on categorization has focused on the importance of a variety of perceptual properties. Intrinsic properties, i.e. invariant object features, such as object shape (e.g., Panis, Vangeneugden, Op de Beeck, & Wagemans, 2008; Panis, Vangeneugden, & Wagemans, 2008) and object size (e.g., Tucker & Ellis, 2001), have been extensively investigated; in addition, intrinsic properties that cannot be visually detected, such as weight (e.g., Brouwer, Georgiou, Glover, & Castiello, 2006; Scorolli, Borghi, & Glenberg, 2009), have also been studied. However, an important property related to both object perception and manipulation has not been extensively studied. To our knowledge there are no studies on adults showing how physical object malleability (from now on consistence) might influence the way humans categorize and represent category members. This strikes us as surprising because consistence is a relevant and peculiar object property. Namely, object consistence is peculiar in that it can be estimated simply by seeing objects, but, in order to be determined with a certain degree of reliability, it requires direct object manipulation. In addition, information on how to manipulate objects, and, in particular, on whether objects are hard or soft, becomes part of our long term knowledge.

The majority of studies on categorization have focused on shape, size, and texture. However, there are some studies which have addressed the role played by consistence and object malleability in categorization. Kourtzi and Shiffrar (2001) manipulated the perceived malleability of primes using curvilinear deformations of malleable tubes. They found that priming effects were more restricted for deformed views of rigid compared to non-rigid

objects, suggesting that rigid objects are not perceived as continuous and dynamical events. Categorization studies on infants have shown that children are sensitive to differences in object consistence. Gibson and Walker (1984) observed that infants as young as 1 month of age were able to extract information about the softness or rigidity of an object merely through exploration by the mouth, and were able to use this information in a subsequent visual recognition test in which they were presented with objects moving in a pattern which was characteristic either of a rigid object or of an elastic, spongy object. Rochat (1987) presented neonates and 2 and 3-month-olds infants with objects which were identical in shape, texture, and dimension but which varied in consistence. Objects were either introduced into their mouth for mouthing or into their hands for grasping. In this way he also manipulated the manual or oral modality of response to the objects, and recorded the positive pressure variations the infants applied to the objects. He demonstrated that the consistence of an object influences the frequency and pattern of oral and manual actions as early as from birth. Namely, infants respond haptically in a different way to hard and soft objects, and this difference is modulated by the response modality, oral or manual. This result indicates that infants' behaviour is not under the control of reflexive mechanisms but is rather sensitive to affordances emerging from objects. Overall, results on neonates and infants reveal that the sensitivity to object consistence develops quite early.

Further studies have focused on consistence as a relevant property for the categorization of objects by children. For example, properties associated with consistence have been studied in the context of children's induction. Kalish and Gelman (1992), investigating preschoolers' understanding of the properties associated with material (e.g. wood, cotton) and object (e.g. chair, pillow) categories, found that children consistently made inductions based on the items' material when required to predict texture and fragility.

Even more relevant to our aims than work on induction are studies investigating the so-called shape bias in categorization. Since the seminal work of Landau, Smith and Jones (1988), a variety of experiments have provided evidence in favour of the shape bias, that is the tendency to extend new labels to objects similar in shape rather than in size, colour and texture. According to the Attentional Learning Account (ALA), children tend to associate count nouns with shape categorization, and the higher the number of count nouns they possess, the stronger their shape bias (Smith, 2000). Importantly, this bias is probably due to the fact that action is strictly related to objects' shape, and that the way we act on them changes how aspects of shape are processed and remembered (Smith, 2005). This bias, which is already present in 2-year-olds, becomes more robust with age and with age it becomes more specific to artefacts rather than to substances and animals. Thus, it has been shown that the shape bias is modulated by the syntactic construction of the word, as well as by the object perceptual properties. For example, children classify objects endowed with animacy cues, such as objects with eyes, by both shape and texture, whereas they classify eyeless objects only on the basis of shape (Jones, Smith & Landau, 1991), foods on the basis of colour (e.g., studies with monkeys by Santos, Hauser & Spelke, 2001), and substances on the basis of material.

Importantly to our aim, the shape bias has received a considerable amount of experimental support regarding 2 year-olds, whereas the material bias for non-solids is not equally well documented and it seems to emerge later, around the age of 3 (Soja, 1992). In a recent study, Yoshida and Smith (2005) taught 2-year-old Japanese children novel names for solids in shape-based categories and novel names for non-solids in material-based categories. In the English language, count nouns are typically associated with solidity, and mass nouns with non-solids; however, this is not the case for Japanese. Two training conditions were present: in the training condition with the correlated linguistic cue, a different word for solid

and nonsolid exemplars was used; in the other condition the exemplars were named using the same expression. During the test phase the children were shown a new exemplar and told a new name, and were asked to use it to name one out of three entities, which matched the exemplar in material, colour or shape. Results showed that, independently of the training condition, children extended names for solids on the basis of shape. In contrast, performance with non-solids depended on the training condition: children who received redundant linguistic cues extended names on the basis of material more than those who did not receive cues, not only when linguistic cues were present during the test but also when they were absent. In addition, only children trained with correlated linguistic cues tended to extend labels to non-solids on the basis of material at levels reliably greater than chance.

Ellis and Oakes (2006) presented 14-month-old infants with objects that could be categorized by shape (balls vs. blocks) or material (soft vs. hard). Infants who were more acquainted with categorization at a superordinate level or who had larger receptive vocabularies categorized the objects by material as well as by shape, in a flexible way, whereas other infants tended, primarily, to form categories based on shape. Importantly, results regarding material are not as clear as those regarding shape. Overall, studies focusing on object consistence were conducted mainly in the developmental areas. Therefore, the tasks were either preferential looking tasks or word extension tasks. However, word extension tasks might be influenced by Whorfian phenomena, that is, by the correlation between linguistic cues and specific perceptual properties (for an example on color, see Masharov & Fischer, 2006). As shown by Yoshida and Smith (2005), while a specific kind of linguistic training does not have much influence on the shape bias, it does influence material-based categorization.

Our work investigates the role of object consistence in adults. In order to avoid the influence of linguistic information, we used images of objects and standard categorization

tasks at a superordinate level. Literature on children has shown that mass nouns elicit material-based categorization, whereas count nouns lead to shape-based categorization. However, adults might be able to detect and retain more fine distinctions between objects. It is demonstrated that artefacts are typically more associated with the shape bias compared to natural objects. One of the reasons this occurs might be the fact that artefact shapes, such as their way of moving (i.e., Mandler, 1992), are more rigid and more clearly marked, whereas within-category distinctions between different natural objects are more fuzzy. This idea is in keeping with the proposal, formulated by Humphreys, Riddoch and Quinlan (1988), that natural objects have a higher within-category similarity than artefacts. Humphreys and colleagues (1988) have shown that responses to pictures of fruit and vegetables (“structurally similar” objects) were slower compared to the responses to pictures of clothing and furniture (“structurally dissimilar” objects). This difference in structural similarity was greater for picture naming than for superordinate categorization of pictures. If the theory according to which natural objects are more structurally similar than artefacts is true, and if people are sensitive to fine distinctions in consistence, then we should find more marked differences between soft and hard artefacts than between soft and hard natural objects.

The question we intend to address in this paper is whether information on object consistence is automatically activated in adults across different categorization tasks and different response modalities. In other words, we hypothesize that, while observing images of objects, we simulate an interaction with them, and we predict that this simulation is so fine-grained as to be sensitive to differences in object consistence. The simulation theory (Gallese & Goldman, 1998; Jeannerod, 2007) has its neurophysiological basis in the recent discovery, in monkeys as well as in humans, of two kinds of visuomotor neurons: canonical and mirror neurons (see Gallese, Fadiga, Fogassi & Rizzolatti, 1996; for a review see Rizzolatti & Craighero, 2004). Of particular relevance for our aims are canonical neurons, which

discharge during both the execution of specific object-directed actions and during the visual presentation of graspable objects, even when a grasping movement is not required. In our work we also intend to explore whether information on consistence is used to distinguish between different kinds of concepts (artefacts and natural objects).

To address these issues we devised three experiments. Across the experiments we used a categorization task, but we manipulated the relevance of consistence to the task. In Experiment 1 participants were required to decide whether pictures of objects represented hard or soft objects, thus consistence was relevant to the task; in Experiments 2 and 3 the task consisted in categorizing objects into artefacts or natural objects, thus it did not require consistence to be directly accessed. We also manipulated the response modality as follows. In Experiments 1 and 2 we asked participants to respond by grasping either a soft or a hard tennis ball, in order to enhance information related to object manipulation. The use of a soft vs. a hard ball was manipulated between blocks but within participants, because we thought that the sensitivity to such a subtle tactile dimension could be detected only by reducing the variability across subjects. In Experiment 3 we required participants to respond by using a simple key pressure, assuming that this modality of response should not directly activate information on object consistence.

On the basis of this theoretical framework, we advanced the following predictions. Across all experiments we predict a main effect of consistence and an interaction between consistence and kind of object. If we simulate interacting with objects while seeing them, then hard objects should be processed faster than soft ones, as in real life. The kind of grip that hard objects evoke requires less time to be executed and it is less complex; in addition, it does not require the hand to surround the object for a while. This effect of consistence should be more salient for artefacts than for natural objects.

The comparison between the three experiments will allow us to verify whether consistence is activated independently of the kind of task and from the response modality. If consistence is activated independently of the kind of task, we should obtain the same results across the three experiments, that is, the effect should emerge even in tasks which simply require the categorization of objects into artefacts and natural objects. If consistence is activated independently of the response modality, we should obtain the same results across the three experiments, that is, the effect should emerge even in tasks implying a simple key pressure as response modality.

Finally, by comparing the three experiments we aim to explore to what extent participants are sensitive to the response modality. Namely, participants could be sensitive either to fine details or to broad differences concerning the modality of response. If they are sensitive to fine details, a difference should emerge between grasping the soft ball, grasping the hard ball and pressing the key to answer; if they are sensitive to broad differences we should only find a difference between ball grasping and key pressing.

Experiment 1

The aim of the first experiment is to verify whether participants are sensitive to differences in object consistence. We intended to verify this in an experiment in which consistence was relevant to the task, (participants were required to distinguish between soft and hard objects) and in which a response modality enhancing aspects related to object manipulation was used (participants responded by grasping soft vs. hard balls). In addition, we intend to verify whether consistence modulates the difference between artefacts and natural objects, and whether it is more salient for the first than for the latter.

Method

Participants. Twenty participants (mean age 22.8 years) took part in the experiment. All subjects had normal or corrected-to-normal vision and spoke Italian as their first language. All were naive as to the purpose of the experiment, gave informed consent and received money for their participation.

Apparatus and stimuli. Participants sat in a darkened room in front of a 17-inc. colour monitor (the eye-to-screen distance was approximately 52 cm). E-Prime 1.1 software was used.

The experimental stimuli consisted of twenty-four colour pictures of common graspable objects (see Appendix A). The images of the objects are reported on this website: http://laral.istc.cnr.it/borghi/Consistence_stimuli.pdf. All the objects were large and would normally be grasped with a power grip. There were four categories (soft-natural objects, soft-artefact objects, hard-natural objects, hard-artefact objects), with six objects for each class. Each object was presented six times in each session.

In order to select the target objects a pilot study was run. Sixteen independent raters were asked to evaluate the consistence of a list of forty colour pictures of common objects, including soft and hard objects, both natural and artefacts, on a seven-point Likert scale (with 1 = extremely soft and 7 = extremely hard). We selected twenty-four objects (twelve artefacts and twelve natural) which, according to all raters, were judged as very soft ($M = 2.11$) and very hard ($M = 5.85$). Twelve of the twenty-four objects were artefacts (six very soft and six very hard) and twelve were natural (six very soft and six very hard).

The response means of the Likert scale value for the selected objects were entered into a within-subject one-way ANOVA with the factor Object Category (artefact, natural). The analysis did not reveal a main effect of object category, $F(1, 22) = .108$, $MSe = 4.39$, $p = .75$ (artefact objects: 4.13; natural objects: 3.84).

Moreover, another rating was carried out in order to check if the twenty-four selected objects differ in consistence. Twenty independent raters were asked to evaluate the consistence of the selected objects on the same seven-point Likert scale. In particular, ten raters were asked to judge the consistence of the twelve artefact objects and ten raters were asked to judge the consistence of the twelve natural objects (see Appendix A).

Response means for artefacts and for natural kinds were separately entered into a within-subject one-way ANOVA with the factor Consistence (hard and soft). The ANOVA on artefact objects showed the main effect of object consistence, $F(1, 10) = 2505.6$, $MSe = 0.03$, $p < .00$ (hard objects 6.55; soft objects 1.52). Similarly, the ANOVA on natural objects showed the main effect of object consistence, $F(1, 10) = 826.14$, $MSe = 0.08$, $p < .00$ (hard objects: 6.42; soft objects: 1.62).

Three more ratings were carried out in order to test if the selected objects differ in familiarity, visual complexity and typicality. In each rating, sixteen independent raters were asked to evaluate the familiarity, visual complexity or typicality of each object on a seven-point Likert scale (with 1 = minimum and 7 = maximum). Response means were entered into a 2 x 2 within-subject ANOVA with the following factors: Consistence (hard and soft) and Category (artefact and natural). The three analyses revealed no significant main effect or interaction (the p -values of non-significant interactions between consistence and category were: familiarity $p = .80$; visual complexity $p = .97$; typicality $p = .69$). These results demonstrated that the twenty-four selected objects do not differ concerning familiarity, visual complexity and typicality, and they also showed that there is no difference between artefact and natural objects, nor between hard and soft objects.

In order to ensure that the lack of differences among Likert scale values really reflects lack of differences related to reaction time, we carried out a brief experiment. Ten independent raters were asked to carefully look at the objects: first they were shown twelve

of the discarded objects as practice block, then were shown the twenty-four selected objects. Each trial began with a fixation point (+) displayed for 1000 ms in the centre of the screen. Then, a target object was shown and remained on the centre of the screen until a response had been made or 2000 ms had elapsed. The participants had to push the key-response as soon as they recognized the object and to name it aloud. Response means were entered into a 2 x 2 ANOVA with the following factors: Consistence (hard and soft) and Category (artefact and natural). The analyses revealed no significant main effect (consistence $p = .63$; category $p = .30$) nor interaction ($p = .16$). This result confirmed what found with the Likert scales ratings, as it showed that there was no difference between artefact and natural objects, nor between hard and soft objects.

Procedure. Participants were required to decide as fast and as accurately as possible whether the stimulus was soft or hard by pressing one of two designated keys. Half of the participants were required to make a right-hand key-response if the target object was soft and a left-hand key-response if it was hard, whereas the opposite hand-to-category arrangement was applied to the other half.

Participants were required to grasp a ball during the task in order to enhance information related to object manipulation and to activate aspects related to manipulation, so that a simulation effect was induced. In one condition subjects had to push the key-response while grasping soft balls in both hands; in the second condition, they had to respond while grasping hard balls.

The experiment was run in two sessions. Each session consisted of one practice block of 24 trials and one experimental block of 144 trials. Each trial began with a fixation point (+) displayed for 1000 ms in the centre of the screen. Then, a target object was shown and remained on the centre of the screen until a response had been made or 2000 ms had elapsed. Participants received feedback on reaction time (RT) after pressing the right or the wrong key

(the reaction time value or “Error”, respectively). The next trial began after the feedback disappeared.

The order of conditions was balanced across participants. After each session, participants could take a brief break. Overall the experiment lasted about 20/25 minutes.

Results

Reaction times. Reaction times (RTs) for incorrect responses and RTs more than two standard deviations from each participant’s overall mean were excluded from the analysis (8.8 %). The correct RTs were entered into two ANOVAs, one on the participants’ data and one on the materials. The first ANOVA had three within-subject factors: Object Consistence (hard and soft), Category (artefact and natural), and Ball Consistence (hard and soft). In the materials ANOVA there were four factors: Response Hand (right and left) as between items factor, and Consistence (hard and soft) Category (artefact and natural), and Ball Consistence (hard and soft) as within items factors.

In the ANOVA, the analysis revealed two main effects: consistence, which was significant in the analysis on participants, $F^1(1, 19) = 5.69, MSe = 359, p = .028$, but not on materials ($p = .23$), and category, which was significant both in the analysis on participants (indicated by F^1) and on materials (indicated by F^2), $F^1(1, 19) = 87.18, MSe = 733, p < .0001$, $F^2(1, 20) = 53.18, MSe = 707, p < .0001$. In particular, responses were faster when the object was hard and slower when stimuli were soft (537 vs. 544 ms, respectively). The second main effect showed that participants responded faster to the artefacts (521 and 520 ms; analysis on participants and on materials, respectively) and slower to the natural stimuli (561 and 560 ms; analysis on participants and on materials, respectively). Importantly, the participants analysis also revealed a significant interaction between consistence and category, $F^1(1, 19) = 5.61, MSe = 447, p = .029$. The post-hoc Newman-Keuls test showed that the artefacts were identified faster when the objects were hard rather than soft, whereas no

difference was found with the natural stimuli (513 vs. 528 ms, and 561 vs. 560 ms, respectively) (see fig. 1).

Insert Fig. 1 about here

Errors. Two identical ANOVAs were run for error data.

The main effect of category was significant both in the analysis on participants (indicated by F^1) and on materials (indicated by F^2), $F^1(1, 19) = 26.54$, $MSe = 4.75$, $p < .0001$; $F^2(1, 20) = 24.25$, $MSe = 17.33$, $p < .0001$. That is, participants made fewer errors with the artefacts ($M = 0.73$ and $M = 2.42$) than with the natural stimuli ($M = 2.5$ and $M = 8.33$).

Discussion

The results of Experiment 1 show that hard objects are identified faster than soft objects: this effect matches the simulation theory according to which the sight of an object activates the corresponding motor response. Our results suggest that, while seeing an object, we simulate a real interaction with it: namely, we are faster to simulate the grasping of a hard object, while we are slower to grasp a soft object. This result seems to support the idea that the kind of grip that hard objects evoke requires less time to be executed and it is less complex. The advantage of objects graspable with a power grip over objects graspable with a precision grip was found also in previous experiments in our lab (Bazzarin, Borghi, Tessari, & Nicoletti, 2007; Borghi, Bonfiglioli, Lugli, Ricciardelli, Rubichi, & Nicoletti, 2007). We interpreted it in the framework of studies which show that grasping an object with a precision grip is more complex and time consuming than grasping an object with a power grip (Ehrsson, Fagergren, Jonsson, Westling, Johansson, & Forssberg, 2000). In the same way, in three experiments

Vainio, Symes, Ellis, Tucker, and Ottoboni (2008) demonstrated that power grasping requires less execution time than precision grasping, probably due to the fact that precision grasps are more complex and time consuming. In our experiments, all the objects were large and would normally be grasped with a power grip. The result seems to suggest that power grip of soft objects is halfway between power grip and precision grip: in order to grasp a soft object, we need to adapt more our hand to the object compared to what happens when grasping a hard object, considering that a soft object (e.g., a tomato or a sponge) undergoes a deformation during grasping, while a hard object (e.g., a coconut or a glass) does not.

However, the sensitivity to object consistence is present only with artefacts, not with natural objects. Namely, the second and most important result we found is the interaction between object consistence and object category. Participants responded to artefacts faster when the objects were hard rather than soft, whereas no difference between hard and soft exemplars was found for natural objects. This reveals that consistence influences the way we represent different kinds of object; namely, it seems we represent artefacts as hard rather than soft, whereas natural stimuli are not modulated by consistence. Thus object consistence seems to be particularly important in the context of object use, not of simple object manipulation.

The final result we found is that categorization was faster when the object was artefact rather than natural, even if the object category was totally irrelevant to the task. This result is in line with what found by VanRullen and Thorpe (2001) who did not detect an advantage of natural objects over artefacts with an ultra-rapid visual categorization task. However, our results are difficult to compare with those of VanRullen and Thorpe as they required participants to categorize animals and vehicles, whereas in our study stimuli consisted of manipulable artefacts and natural objects. More crucially, our result disagrees with results found by Borghi et al. (2007) and by Vainio et al. (2008) who used manipulable objects and

obtained faster response times when the stimuli were natural. Borghi et al. (2007) proposed that natural objects were processed faster because, differently from artefacts, they are associated only with manipulation and not also with functional information. It is possible that the specific task we used, requiring participants to focus on object consistence, activated only manipulation and not functional information – this hypothesis will be verified in Experiment 2. However, this explanation could account for the absence of any difference between artefacts and natural kinds, but not for the processing advantage of artefactual objects over natural ones. Rather, our result can be explained by the “Cascade model” of visual object recognition outlined by Humphreys et al. (1988). The authors proposed that living things have more similar structures than nonliving things. Differences in structural similarity between living and nonliving things may contribute to the differences in identification that can be observed between these categories of objects. Structurally similar objects will activate the structural representations of perceptual neighbours across their category. As a consequence, functional and associative information common to the category is derived quickly, but identification of single exemplars should require more time due to an increased competition between category exemplars. In contrast, structurally dissimilar objects will activate fewer perceptual neighbours. As a consequence, activation of functional and associative information will be slower and less widespread, but individual identification is more efficient, since competition from perceptually and functionally similar neighbours will be reduced (Humphreys et al., 1988; Humphreys & Forde, 2001). In keeping with this view, previous studies found that normal subjects named pictures of living things more slowly than pictures of nonliving things matched for familiarity and name frequency (Humphreys et al., 1988; Lloyd-Jones & Humphreys, 1997; Snodgrass & Yuditsky, 1996). The “Cascade model” can easily account for the slower response times we obtained with natural objects: namely, in order to decide whether an object is hard or soft, processing of single exemplars is required.

Thus, the faster response to artefactual objects compared to natural ones should be due to the fact that identifying individual category exemplars is more demanding for natural objects than with artefacts, due to the fact that natural objects are more similar to each other than artefacts, thus they “compete” more for identification.

Experiment 2

Experiment 2 is aimed at a better comprehension of whether the interaction between object consistence and object category found in Experiment 1 was simply due to the task which required participants to overtly evaluate object consistence, judging whether the displayed object was soft or hard. To rule out this possibility, in Experiment 2 participants were required to categorize stimuli into artefacts or natural objects; no mention was made of object consistence. If consistence is really part of object representation and is automatically activated, then it should influence the performance even when it is irrelevant to the task. In addition, given that the task does not require the accessing of the single exemplars but rather the performance of a superordinate categorization, we predict that the processing advantage of artefacts over natural objects disappears, in line with the Cascade model.

Method

Participants. Twenty participants (mean age 26.1 years) took part in the experiment. All subjects had normal or corrected-to-normal vision and spoke Italian as their first language. As in Experiment 1, all subjects were naive as to the purpose of the experiment, gave informed consent and received money for their participation.

Apparatus, stimuli and procedure. The stimuli were the same used in Experiment 1. However, in the present experiment, participants were required to evaluate the category of the target object (artefact or natural) and not the consistence (hard or soft).

Results

Reaction times. Reaction times (RTs) for incorrect responses and RTs more than two standard deviations from each participant's overall mean were excluded from the analysis (6.65 %). The correct RTs were entered into two ANOVAs, one on the participants' data and one on the materials. The first ANOVA had three within-subject factors: Object Consistence (hard and soft), Category (artefact and natural), and Ball Consistence (hard and soft). In the materials ANOVA there were four factors: Response Hand (right and left) as between factor, and Consistence (hard and soft) Category (artefact and natural), and Ball Consistence (hard and soft) as within factors.

In the participants ANOVA, the analysis revealed a main effect of consistence, $F^1(1, 19) = 37.24, MSe = 87, p < .0001$). In particular, responses were faster when the object was hard, and slower when the stimuli were soft (498 vs. 507 ms, respectively), thus replicating the results of Experiment 1. Importantly, the analysis also revealed a significant interaction between consistence and category, $F^1(1, 19) = 55.80, MSe = 159, p < .0001$. The post-hoc Newman-Keuls test showed that the artefact objects were identified faster when they were hard, and slower when stimuli were soft (494 vs. 518 ms, respectively), thus replicating the results of Experiment 1, whereas the natural objects were identified faster when they were soft, and slower when they were hard (495 vs. 501 ms, respectively), (see Figure 2).

Insert Fig. 2 about here

In the materials ANOVA, the analysis revealed a main effect of response hand, $F^2(1, 20) = 14.26, MSe = 87, p = .001$. Participants responded faster when they had to make a right-hand key-response rather than a left-hand key-response ($M = 501$ vs. 508 ms, respectively). In addition, an interaction between response hand and object category, $F^2(1, 20) = 48.86,$

$MSe = 87$, $p < .0001$, showed that artefacts were identified particularly faster when the response-key was right as opposed to left (499 vs. 520 ms, respectively). Conversely, there was a no significant tendency to identify natural objects more quickly when the response-key was left as opposed to right ($p > .05$). Fig. 3 illustrates this effect.

Insert Fig. 3 about here

Errors. Two identical ANOVAs were run for error data.

In the participants ANOVA, the analysis revealed a significant interaction between consistence and category, $F^l(1, 19) = 45.225$, $MSe = 0.84$, $p < .0001$. The post-hoc Newman-Keuls test showed that artefact objects were identified more accurately when they were hard ($M = 0.43$) rather than soft ($M = 1.5$); conversely, natural objects were identified more accurately when they were soft ($M = 0.48$) rather than hard ($M = 1.35$). This result is in accord with a trend already present in the error analysis of Experiment 1 and it is congruent with RT analysis. In the materials ANOVA, there were no main effects or interactions.

Comparison between Experiment 1 and 2

The correct RTs of Experiment 1 and Experiment 2 were entered into a three-way ANOVA, with Task (consistence and category evaluation) as between factor, and Consistence (hard and soft) and Category (artefact and natural) as within factors.

The analysis revealed three main effects: task ($F(1, 38) = 7.25$, $MSe = 7977$, $p = .01$), consistence ($F(1, 38) = 25.18$, $MSe = 108$, $p < .0001$), and category ($F(1, 38) = 23.77$, $MSe = 108$, $p < .0001$). In particular, responses were faster when participants were required to categorize objects as artefacts or natural objects and slower when they had to categorize objects as hard or soft (502 vs. 517 ms, respectively). The second main effect showed that

responses were faster when the object was hard and slower when stimuli were soft (517 vs. 525 ms, respectively). The third main effect demonstrated that participants responded faster to the artefacts than to the natural stimuli (513 vs. 529 ms, respectively). The analysis also revealed two significant interactions: the interaction between task and category ($F(1, 38) = 52.81, MSe = 413, p < .0001$) and between consistence and category ($F(1, 38) = 32.65, MSe = 149, p < .0001$). The first post-hoc Newman-Keuls test showed that responses in Experiment 1 were faster when the object was an artefact and slower when it was natural (520 vs. 559 ms, respectively), and that participants categorized natural objects faster in Experiment 2 and slower in Experiment 1 (498 vs. 559 ms, respectively). Moreover, the second post-hoc Newman-Keuls test showed that the artefacts were identified faster when the objects were hard rather than soft (503 vs. 523 ms, respectively).

Discussion

In line with the simulation theory, RTs of Experiment 2 were faster when the object was hard rather than soft, thus replicating the results of Experiment 1. However, as in Experiment 1, this effect was totally due to artefacts. Namely, our results revealed an interaction between object consistence and object category: artefacts were identified faster and more accurately when they were hard rather than soft. Conversely, natural objects were identified faster and produced less errors when they were soft rather than hard. This result not only replicated that of Experiment 1, thus confirming that we represent artefacts as hard rather than soft, but also suggested an opposite pattern as far as natural objects were concerned. That is, we perceive natural objects as soft rather than hard.

Interestingly, we did not replicate the difference between artefacts and natural objects. This is in keeping with the idea that, due to the task, participants did not need to process the single exemplars but performed a broad categorization task, as predicted. This should lead to an advantage of natural objects over artefacts. Contrary to this prediction, we did not find this

advantage of natural over artefactual objects but we found no difference between the two categories. This is probably due to the fact that responding while holding balls enhances manipulability, and this might interfere with the processing of natural objects more than with the processing of artefacts. The idea that seeing objects entails a simulation of the interaction with them is confirmed by the advantage of right over left hand responses with artefacts, an advantage which does not occur with natural objects. This suggests that, when the task does not require participants to focus on object consistence (Experiment 2), artefacts activate the simulation of grasping in order to use them, which is consistent with the activation, prompted by artefacts, of the right hand, typically used for skilled and precise actions. This effect was confined to artefacts, confirming the interference of holding balls with processing of natural objects.

In Experiment 1 and 2 participants were required to grasp hard or soft balls during the task. The response modality was employed in order to enhance information related to object manipulation. Results showed that participants were not sensitive to subtle differences in response modalities such as the difference between grasping a soft and a hard ball. A possible explanation is that the final goal of their action was the same in the two cases, and consisted in “pressing a key having something in the hand”. Namely, in Experiments 1 and 2 participants had to hold the ball which was attached to the key on the keyboard. Previous evidence in our laboratory on language processing reveals that we are sensitive to the differences in hand posture between “pressing a key holding something in the hand” vs. “pressing a key with the open hand” (Freina, Baroni, Borghi & Nicoletti, 2009).

In Experiment 3 we intended to investigate whether using a completely different response modality which implies a different goal, i.e. key pressure vs. grasping a ball, impacts performance.

Experiment 3

In this experiment, we aimed to verify whether the interaction between object consistence and object category found in the previous experiments was due to the response modality which activated aspects related to object manipulation. Thus, participants were instructed to press the key-response directly with their fingers, without grasping soft or hard balls in both hands. If inferred information on consistence is automatically activated, we expect it to influence performance even without a response modality which enhances aspects related to object manipulation.

Method

Participants. Twenty students of the University of Bologna (mean age 19.8 years) took part in the experiment. All subjects had normal or corrected-to-normal vision and were native Italian speakers. As in the previous experiments, all subjects were naive as to the purpose of the experiment and gave informed consent.

Apparatus, stimuli and procedure. The stimuli and the type of task were the same as in the previous experiments, the only difference was that subjects had to push the key-response directly with their fingers, without grasping soft or hard balls in both hands.

Results

Reaction times. Reaction times (RTs) for incorrect responses and RTs more than two standard deviations from each participant's overall mean were excluded from the analysis (6.15 %). The correct RTs were entered into two ANOVAs, one on the participants' data and one on the materials. The first ANOVA had two within-subject factors: Object Consistence (hard and soft) and Category (artefact and natural). In the materials ANOVA there were three factors: Response Hand (right and left) as between factor, and Consistence (hard and soft) and Category (artefact and natural) as within factors.

In the participants ANOVA, the analysis revealed two main effects: consistence ($F^1(1, 19) = 40.27, MSe = 55, p < .0001$) and category ($F^1(1, 19) = 6.47, MSe = 485, p = .02$). In particular, responses were faster when the object was hard, and slower when stimuli were soft (480 vs. 491 ms, respectively). Importantly, participants responded faster to the natural stimuli and slower to the artefacts (479 vs. 492 ms, respectively). The analysis also revealed a significant interaction between consistence and category, $F^1(1, 19) = 33.45, MSe = 76.97, p < .0001$. The post-hoc Newman-Keuls test showed that the artefacts were identified faster when the objects were hard rather than soft (481 vs. 502 ms, respectively). As far as natural objects were concerned, however, there was no difference in RTs for soft or hard stimuli (479 vs. 479 ms, respectively). Fig. 4 illustrates this interaction.

In the ANOVA with materials, there were no main effects or interactions.

Insert Fig. 4 about here

Errors. Two identical ANOVAs were run for error data.

The interaction between consistence and category was significant both in the analysis on participants (indicated by 1) and on materials (indicated by 2), $F^1(1, 19) = 12.73, MSe = 2.97, p = .002$, and $F^2(1, 20) = 6.71, MSe = 9.40, p = .02$ (analysis 1 and 2, respectively). In the first ANOVA, the post-hoc Newman-Keuls test showed that natural objects were identified more accurately when they were soft ($M = 1$) rather than hard ($M = 2.85$), whereas no difference emerged with the artefacts (0.75 vs. 1.65, respectively). In the materials ANOVA, the post-hoc Newman-Keuls test showed that hard objects were identified more accurately when they were artefacts ($M = 1.25$) rather than natural objects ($M = 4.75$).

Comparison between Experiment 2 and 3

The correct RTs of Experiment 2 and Experiment 3 were entered into a three-way ANOVA, with Response Modality (grasping balls and no-grasping balls) as between factor, and Consistence (hard and soft) and Category (artefact and natural) as within factors.

The analysis revealed two main effects: consistence, $F(1, 38) = 77.72$, $MSe = 49$, $p < .0001$, and category, $F(1, 38) = 8.51$, $MSe = 480$, $p < .006$. Responses were faster when the objects were hard and slower when stimuli were soft (489 vs. 498 ms, respectively). In addition, participants responded faster to the natural stimuli and slower to the artefacts (489 vs. 499 ms, respectively). The analysis also revealed a significant interaction between consistence and category, $F(1, 38) = 88.40$, $MSe = 77$, $p < .0001$. The post-hoc Newman-Keuls test showed that the artefacts were identified faster when the objects were hard rather than soft, whereas no difference was found with the natural stimuli (487 vs. 510 ms, and 490 vs. 487 ms, respectively).

Discussion

The results of Experiment 3 showed that objects were identified faster when they were hard and slower when they were soft, thus confirming the results of the previous experiments.

Importantly, the categorization was performed faster when the object was natural rather than an artefact. This result disagrees with the results of Experiment 1, but agrees with data of Borghi et al. (2007) and Vainio et al. (2008), and reveals that, even if participants are not sensitive to fine differences in response modality (e.g., the difference between hard and soft balls), they are sensitive to macroscopic postural differences in response modalities (e.g., pressing a key vs. grasping a ball). Even if we did not find a main effect of response modality, the results of Experiments 2 and 3 indicate that the way artefacts and natural objects are processed varies depending on the response modality. As mentioned above, Borghi et al. proposed that natural objects are processed faster because, differently from artefacts, they activate only manipulation and not function information. Indeed, the

recognition of artefacts depends more on functional features than the recognition of natural objects, for which visual features are more relevant. If an artefact activates information not only about how to manipulate it, but also about the functional gestures associated with it, it could be argued that seeing an artefact leads to the simulation not only of the hand gestures required to grasp it, but also of the other gestures required to actually use it. The activation of gestures related to both object manipulation and object use should slow performance with artefacts. This is not the case for natural objects, as they would not activate hand gestures related to object use. Thus, the pattern we found is in keeping with the Cascade model. This model predicts that natural objects are faster with a categorization task which does not require the access to single instances. We did not find the advantage of natural objects over artefacts in Experiment 2, where artefacts and natural objects did not differ. The absence of an advantage of natural over artefactual objects, which would be predicted by the Cascade model, is probably due to the fact that response modality activates manipulation, which interferes with processing of natural objects but not of artefacts. Consistently with this explanation, the advantage of natural objects over artefacts emerges only in Experiment 3, that is, when the response modality does not enhance manipulation. Thus in Experiment 3 artefacts pay a cost, as they involve the activation of both manipulation and function information, whereas natural objects are faster as they elicit only manipulation information. Overall, the fact that in Experiment 2 no difference is found between artefacts and natural objects and that in Experiment 3 artefacts are processed slower than natural objects suggests that, even if we did not find a significant difference between the experiments, the response is affected by the type of response modality, and that it has a different impact on the way we process artefacts and natural objects.

In addition, our results show that the interaction between object consistence and object category is present even with a response modality that does not enhance manipulation.

Namely, participants identified artefacts faster when the objects were hard rather than soft, thus replicating the results of previous experiments.

General Discussion

Our studies fill a gap in research on categorization as they clearly demonstrate the importance of object consistence in different categorization tasks performed by adults. To our knowledge the role of consistence has mainly been investigated focusing on infants' and children's categorical organization. This strikes us as surprising, because of the relevance of this property for interaction with objects.

First of all, we found that we are sensitive to differences in object consistence. This sensitivity to consistence occurred across different categorization tasks and was not modulated by response modalities. Namely, participants detected differences between hard and soft objects independently of whether the task required them to categorize objects by consistence or to categorize them by object kind (artefacts vs. natural objects), and independently of whether they had to respond by pressing a key while grasping either a soft or a hard ball or to respond by pressing a key on a keyboard without holding balls. Given that differences in consistence are not due to factors such as familiarity, visual complexity or typicality, the advantage of hard over soft objects seems to be due to the simulation of a real interaction with an object rather than to a simple semantic association between a property and an object. However, this effect of consistence was present with artefacts, rather than with natural objects. It is therefore plausible that it is linked to grasping for using an object rather than to grasping for simply manipulating it (for a discussion on this issue see Borghi, Bonfiglioli, Ricciardelli, Rubichi, & Nicoletti, 2007).

Secondly, and more crucially, we found that consistence helps to disentangle different kinds of objects. More specifically, we detect differences in consistence more clearly within artefacts than within natural objects. This might be due to the fact that artefacts'

characteristics are perceived as more clearly defined compared to those of natural objects. However, the fact that the interaction between consistence and object kind is maintained across tasks that require subjects to focus either on the single exemplars (Experiment 1) or on superordinate categories (Experiment 2 and 3) suggests that the result is specific for this property, consistence, and it cannot depend simply on the fact that artefacts have higher within category differences.

We believe our study has implications for research on object affordances and for studies on categorization. As to implications for research on affordances, the sensitivity to object consistence of which we provided evidence shows that visual stimuli activate previous sensorimotor interactions with the objects. It also specifies to what extent we are sensitive to fine-grained differences in motor responses. Namely, whereas no difference between responses with soft and hard balls were evident, we found that differences between grasping (both soft and hard balls) and key-pressing responses influenced the categorization of artefacts and natural objects. This is probably due to the fact that, whereas the goal of the action to perform with soft and hard balls was the same (press a key holding something in your hand), the goal of the action to perform in Experiment 3 differed (press a key with your fingers). At a theoretical level, this result seems to favour theories according to which actions are conceived in terms of overall goals rather than of proximal, kinematics aspects (e.g., Hommel, 2009). Curiously, however, there was no clear relationship between the motor response and the object characteristics in terms of consistence. Consider the findings by Tucker and Ellis (2001) with objects graspable with a precision or with a power grip. The authors found a compatibility effect between the object size and the kind of grip (precision vs. power) that objects evoke and the motor response, that is the kind of pressure made on the joystick which could mimic either a precision or a power grip. Differently from them, here no compatibility effect is found between the ball consistence (soft vs. hard) and the object

consistence (soft vs. hard). This might be due to the fact that we form a broad category of hard and soft objects, and we are not sensitive to more subtle differences such as those the balls might activate.

Our results have novel implications for work on categorization. Studies on word extension in children have shown that solids elicit the so-called shape-bias, whereas with nonsolid objects the children tend to focus on differences in material rather than shape. However, results on material are not as clear as results on the shape bias, and are influenced by associations between object properties and linguistic cues. Namely, in English (as in Italian) count nouns tend to direct attention to object shape (shape bias), whereas mass nouns draw attention to consistence (material). In our experiments we focused on solid objects rather than on substances and non-solids, we avoided the use of linguistic cues, and investigated the differences between artefacts and natural objects in simple categorization tasks with adults. Our results clearly showed that consistence represents an important cue which helps to disentangle information associated with artefacts and natural objects. Therefore we believe that models of categorization should be extended to include this very important property. This does not imply that we believe that consistence is a necessary property for artefacts; rather, that it might be relevant to characterize them.

Finally, we believe our results help to better understand the way we represent artefacts and natural objects. Namely, responses to artefacts and natural objects were differently modulated when participants had to hold the ball in their hand compared to when they had to respond by key pressure.

Crucially for us, differences in response modality as well as in task change the way we represent artefacts and natural objects. When the task requires subjects to focus on single exemplars (Experiment 1), our results, in line with the Cascade model, show that natural objects are processed slower than artefacts. When the task implies a broad categorization,

according to the Cascade model natural objects should be faster. This is exactly what we found. Our results were also in keeping with the PACE (pre-semantic account of category-effects) model, a refined account of the Cascade model (Gerlach, Law, Gade, & Paulson, 2000; Gerlach, Law, & Paulson, 2004, 2006; Gerlach, 2009). According to PACE, category effects do not depend only on differences in structural similarity between categories but also on the kind of task. Thus, PACE accounts for our results as it predicts that natural objects are only disadvantaged if the task requires a fine-grained perceptual differentiation among items.

In addition, our results further show that this advantage of natural objects is modulated by the response modality. When the response enhanced manipulation (Experiment 2), responses did not differ between artefacts and natural objects; when the response did not enhance manipulation (Experiment 3), artefacts were categorized slower than natural objects. This supports the view according to which artefacts activate both manipulation and function information (Borghi et al., 2007; Vainio et al, 2008).

Acknowledgements

Many thanks to EMCO (www.emco.unibo.it) group for helpful comments on this work.

This work was supported by the European Community, in project ROSSI: Emergence of Communication in RObots through Sensorimotor and Social Interaction (Grant agreement no: 216125).

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Appendix A

The twenty-four experimental stimuli of common graspable objects.

Soft Objects		Hard Objects	
Natural	Artefact	Natural	Artefact
chicory	bathroom tissue	carrot	bottle
fig	doughnut	cob	flowerpot
lettuce	hat	coconut	glass
mushroom	puppet	cucumber	mug
persimmon	sponge	melon	perfume bottle
tomato	woollen ball	potato	receiver

Figure Captions

Figure 1. Experiment 1. RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

Figure 2. Experiment 2: RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

Figure 3. Experiment 2: RT analysis (material), 2-way interaction between Hand Response (right vs. left) and Object Category (artefact vs. natural).

Figure 4. Experiment 3: RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

Figure 1. Experiment 1. RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

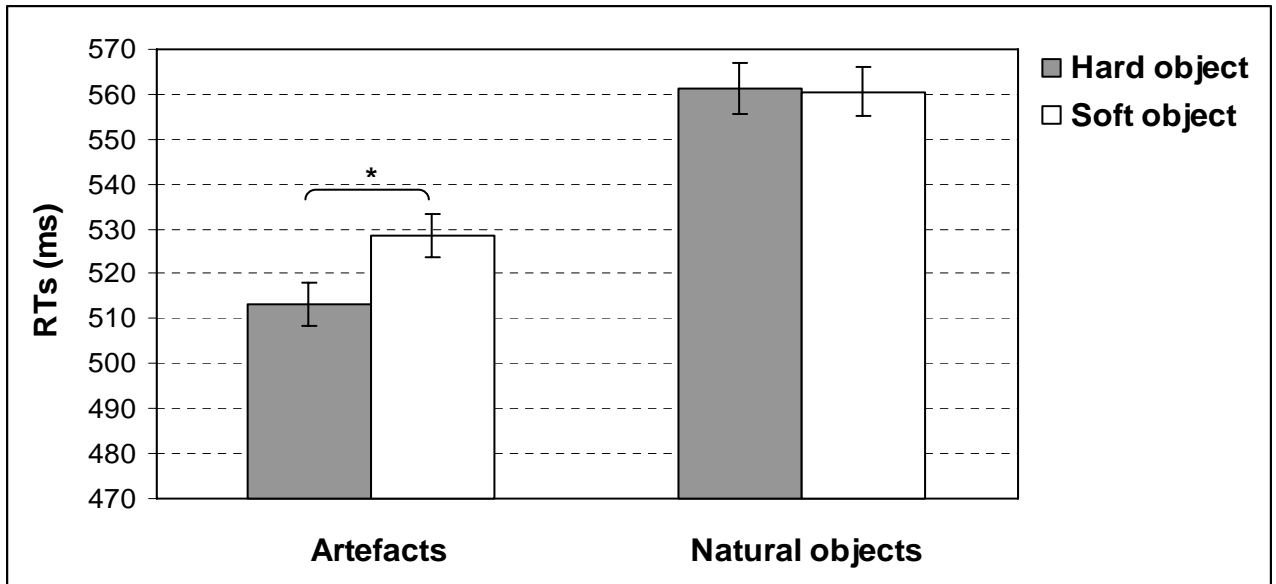


Figure 2. Experiment 2: RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

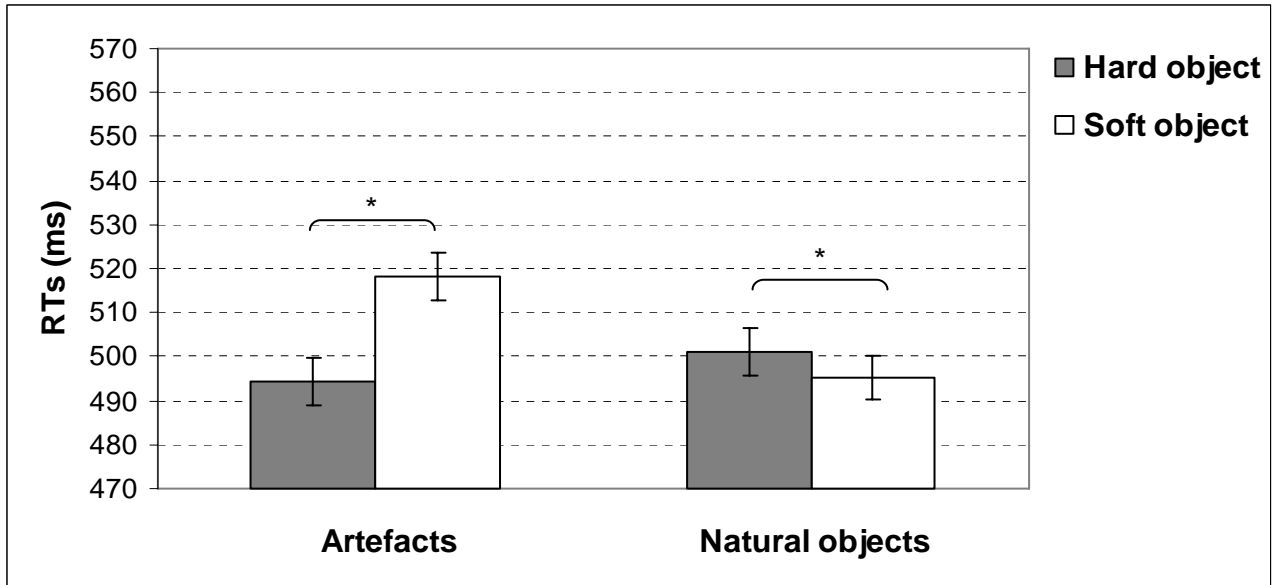


Figure 3. Experiment 2: RT analysis (material), 2-way interaction between Hand Response (right vs. left) and Object Category (artefact vs. natural).

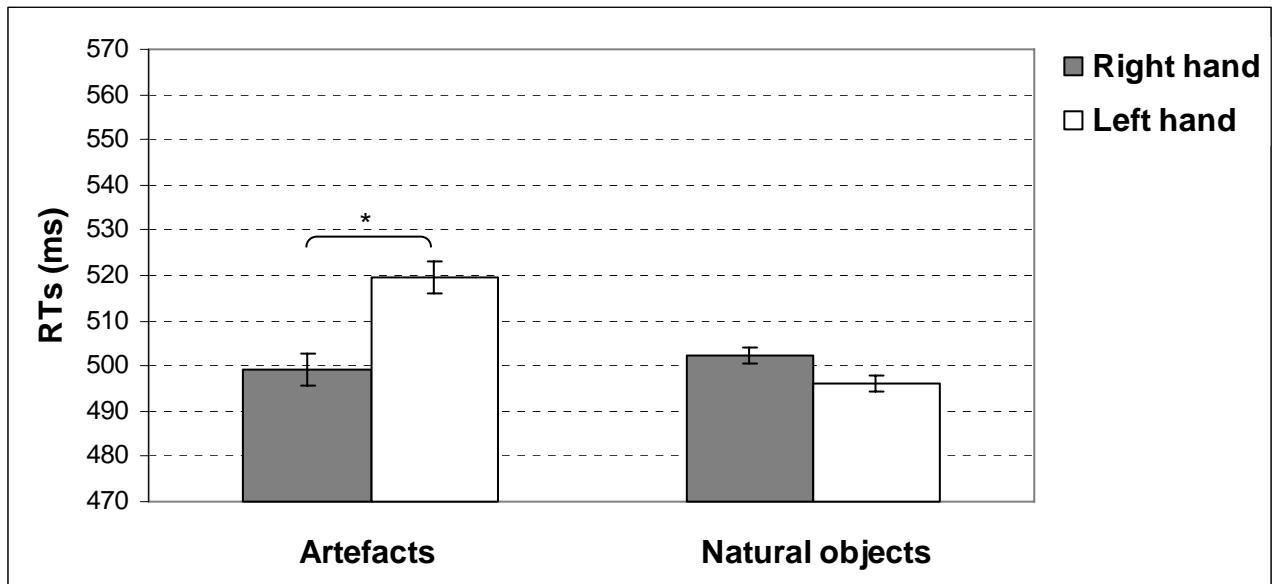


Figure 4. Experiment 3: RT analysis (participants), 2-way interaction between Object Consistence (hard vs. soft) and Object Category (artefact vs. natural).

